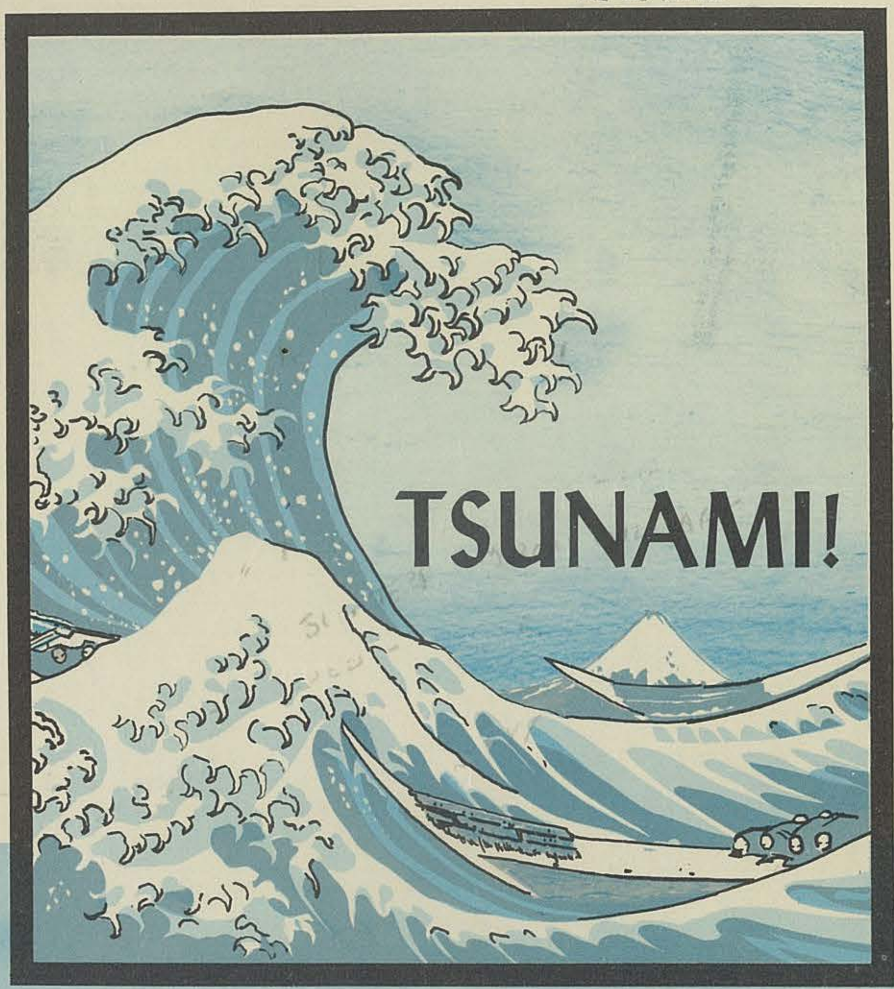
U. S. DEPARTMENT OF COMMERCE • Coast and Geodetic Survey

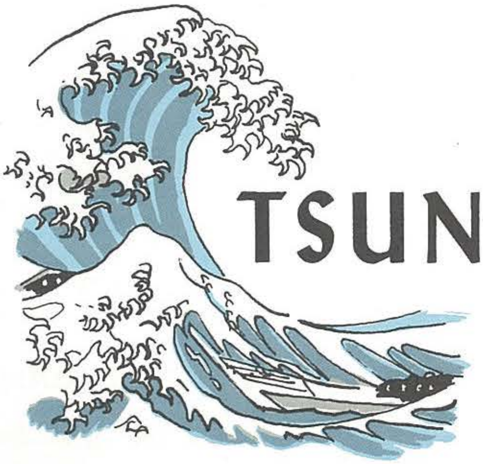
B. L. Keck

津波



The story of the

SEISMIC SEA-WAVE WARNING SYSTEM



TSUNAMI!

The story of the SEISMIC SEA-WAVE WARNING SYSTEM

U.S. DEPARTMENT OF COMMERCE
John T. Connor, *Secretary*

COAST AND GEODETIC SURVEY
H. Arnold Karo, *Director*

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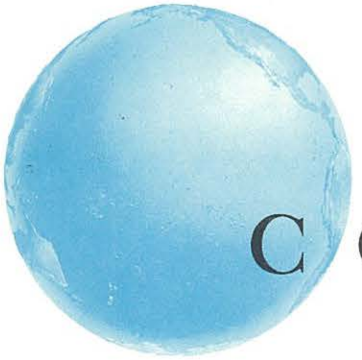

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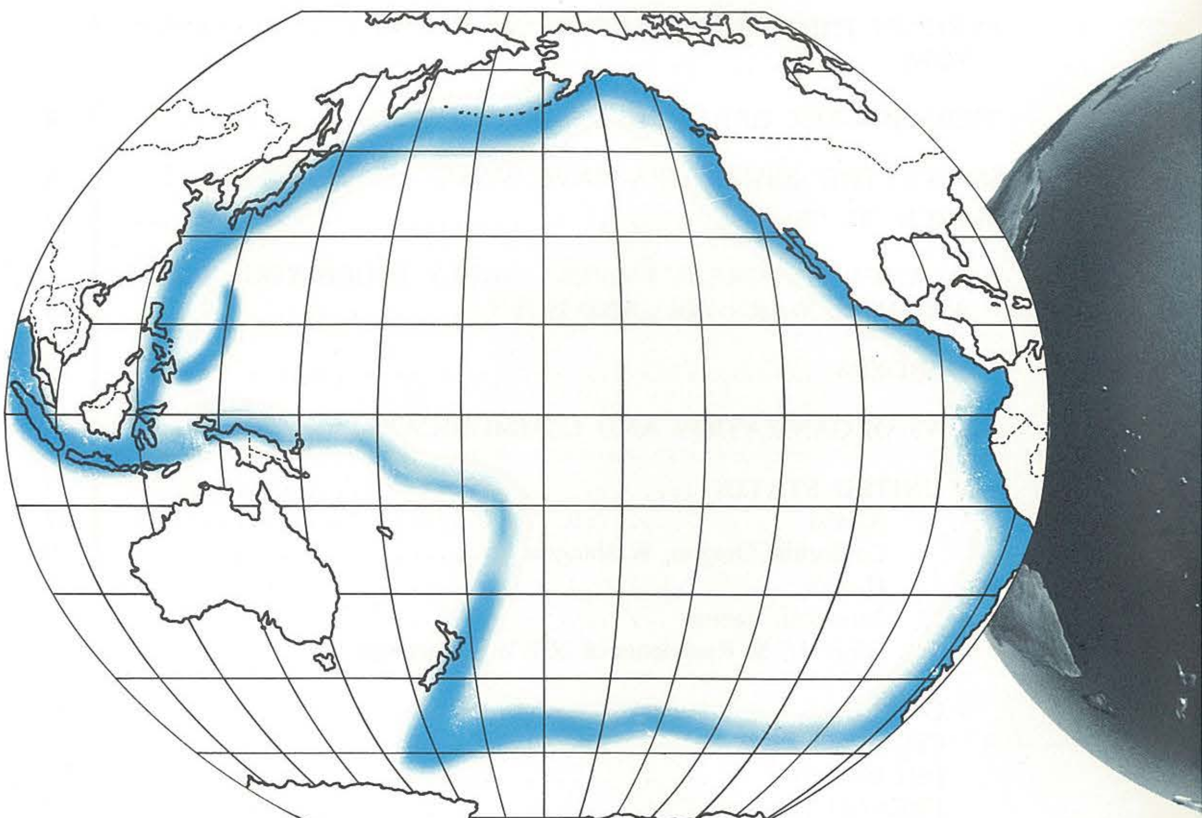


the great waves have

perhaps your town has never been destroyed. But, in March 1964, waves destroyed much of Valdez, Alaska, and brought extensive destruction and loss of life to Crescent City, California. The same waves touched Hawaii, Chile, and Japan.

They were seismic sea-waves, the destructive oceanic offspring of earthquakes (or seisms) and volcanic eruption. Man has lived with the terrible waves since he first settled on the islands and continental rims of oceans, for they have come again and again, bringing fear, catastrophe, and death to thousands.

And as they are born of the cataclysmic changes of our planet, the waves occur most often in the Pacific. Around this largest of oceans runs a zone of extreme seismic activity; it circles the Pacific, its regions of structural (or tectonic) seismicity decorated by the volcanic "Ring of Fire."

This circum-Pacific seismic belt trends along the major geologic faults, or fractures, and the deep oceanic trenches of island arcs, from the south of Chile, up the Pacific coasts of South and Central America and the United States, turning westward along the Aleutian Island arc, then southward through Japan and the Philippine Republic; here it branches westward to Malaysia and Indonesia, and eastward through New Guinea, the southern island groups, and New Zealand.

It is the most active seismic feature on our planet, and from the convulsions of endless alteration have come a legion of destructive oceanic offspring—the great waves of the Pacific.

Every island and coastal settlement in the Pacific Ocean area is vulnerable to the onslaught of seismic sea-waves. The waves of 1868 and 1877 devastated towns in northern Chile, and caused death and damage across the Pacific. A series of seismic sea-waves generated by the eruption and collapse of Krakatoa in 1883 killed more than 36,000 persons in the East Indies. Japan lost 27,000 lives to the wave of 1896, and 1,000 more to that of 1933. There have been hundreds more whose effects were less spectacular but which took many lives and did much damage.

Some call them "tidal waves," a name as misleading as it has been persistent; the great waves are not related to the tides. The Japanese, whose islands have felt the destructive power of the great waves for generations, give us the name used internationally: TSUNAMI.*

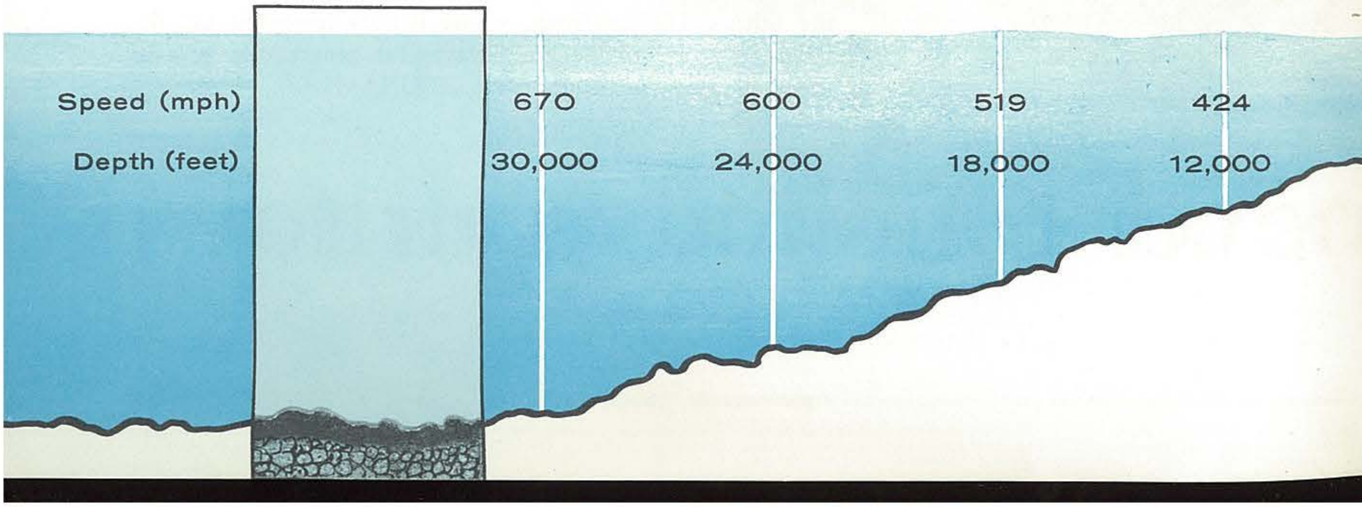
never touched your town

* pronounced: "soo-nóm-ee"

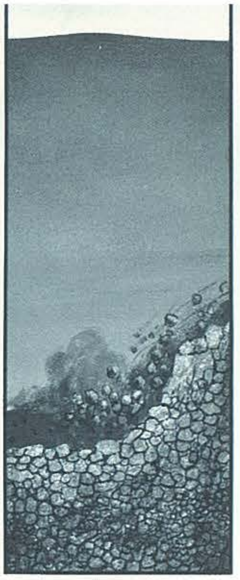
The phenomenon we call "tsunami" is a series of traveling ocean waves of extremely long length and period. In the deep ocean, their length from crest to crest may be a hundred miles or more, their height from trough to crest only a few feet. They cannot be felt aboard ships in deep water, and they cannot be seen from the air. But the kinetic energy—the energy of movement—represented by a tsunami is impressive: a tsunami "feels the bottom" even in the deepest ocean, and it appears that the progress of this imperceptible series of waves represents the movement of the entire vertical section of ocean through which the tsunami passes. In the deep ocean they may reach speeds of 600 miles per hour.

As the tsunami enters the shoaling water of coastlines in its path, the velocity of its waves diminishes and wave height increases. The arrival of a tsunami is often (but not always) heralded by a gradual recession of coastal water, when the trough precedes the initial crest; or by a rise in water level of about one-half the amplitude of the subsequent recession. This is nature's warning that more severe tsunami waves are approaching. It is a warning to be heeded, for tsunami waves can crest to heights of more than 100 feet, and strike with devastating force.

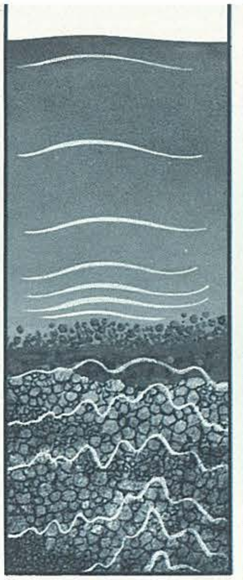
TSUNAMI— THE



VERTICAL DISPLACEMENT



SUBMARINE AVALANCHES



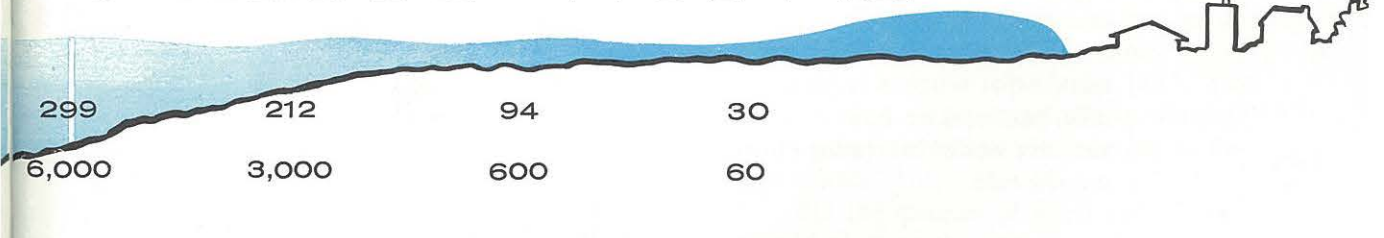
LONG-PERIOD EARTHQUAKE WAVES

RESONANCE OF TRENCH WATER

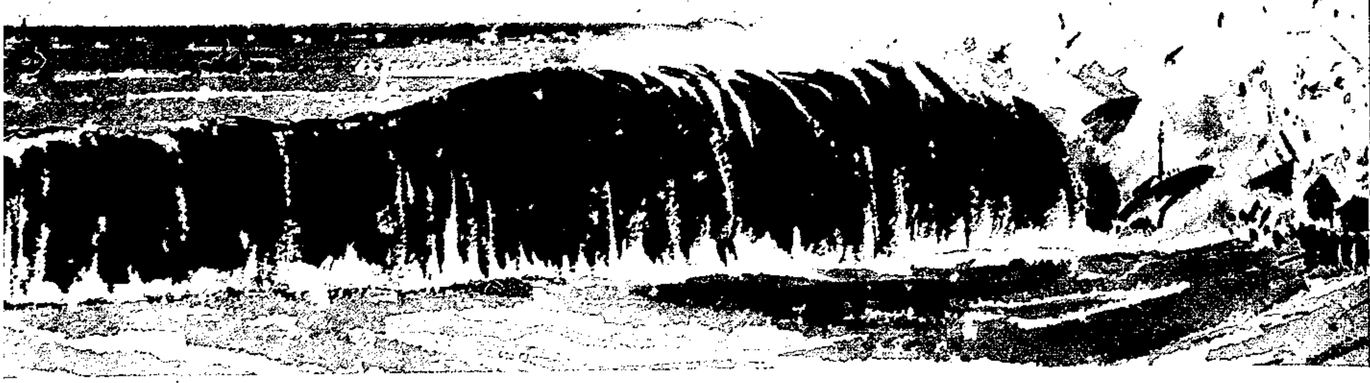
Tsunamis are believed to originate as vertically displaced columns of ocean water, but the displacing agent has not been positively identified. Seismic or volcanic alterations of the ocean floor, provided they impart some vertical movement to the water column, may cause tsunamis. It has also been postulated that submarine avalanches on the slopes of the Pacific trenches produce tsunamis.

Some investigators have turned to long-period ground waves which sometimes accompany large earthquakes, as possible generators of tsunamis. Deformation of the sea floor as these waves travel across it could reach sufficient amplitude to produce large displacements at the water surface, particularly in the region of troughs or trenches. It is possible that long-period earthquake waves generate tsunamis by setting up resonant oscillations of trench water, with consequent displacements at the surface of the sea.

GREAT WAVE



Tsunami speed is determined solely by water depth, and this fixed relationship makes it possible to forecast tsunami arrival times for distant locations. The tsunami illustrated here, although somewhat exaggerated in the vertical dimension, is characteristic.

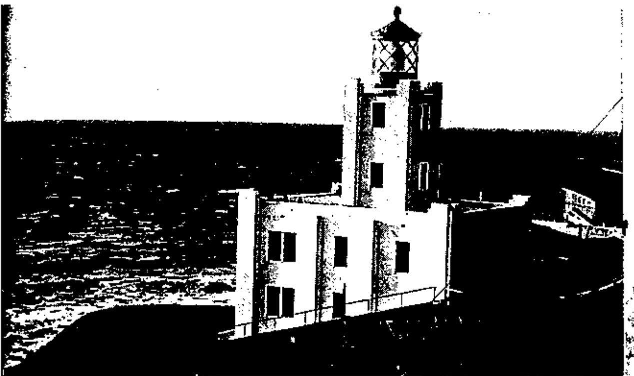


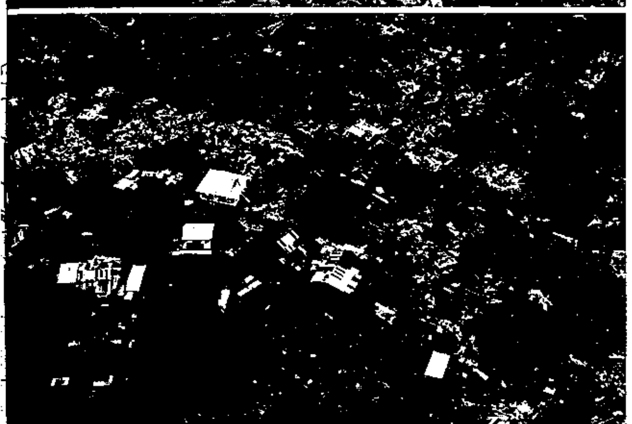
Although it has been established that a relationship exists between seismic or volcanic disturbances and tsunamis, the nature of this relationship is not well-defined. Tsunami magnitude appears to be a function of earthquake magnitude and depth, water depth in the region of tsunami generation, extent and velocity of crustal deformation, and efficiency of energy transfer from the earth's crust to sea water; but the specific effect upon tsunamis of these independent factors is imperfectly understood.

The speed of tsunamis varies with water depth, and it is this relationship which permits prediction of tsunami arrival times at all points in the Pacific Ocean area. But no definite correlation has been possible between the configuration of specific regions of the ocean floor and tsunami configuration in those regions. It is not completely clear, for example, why a tsunami's waves may be of negligible size at one point along a coast, and of much larger proportions at other coastal points nearby. Nor is it possible to predict whether the destructive component of a tsunami will lie in its powerful surge across a beach, or in a gradual rising of sea level followed by a rapid draining back to sea.

Thus it is impossible to say with any certainty what shape a tsunami will assume at specific locations, or how it will accomplish its destructive work. In treating of tsunamis, exceptions are the rule.

Photographs courtsey of: U.S. Coast Guard, U.S. Air Force, Press Association Incorporated.





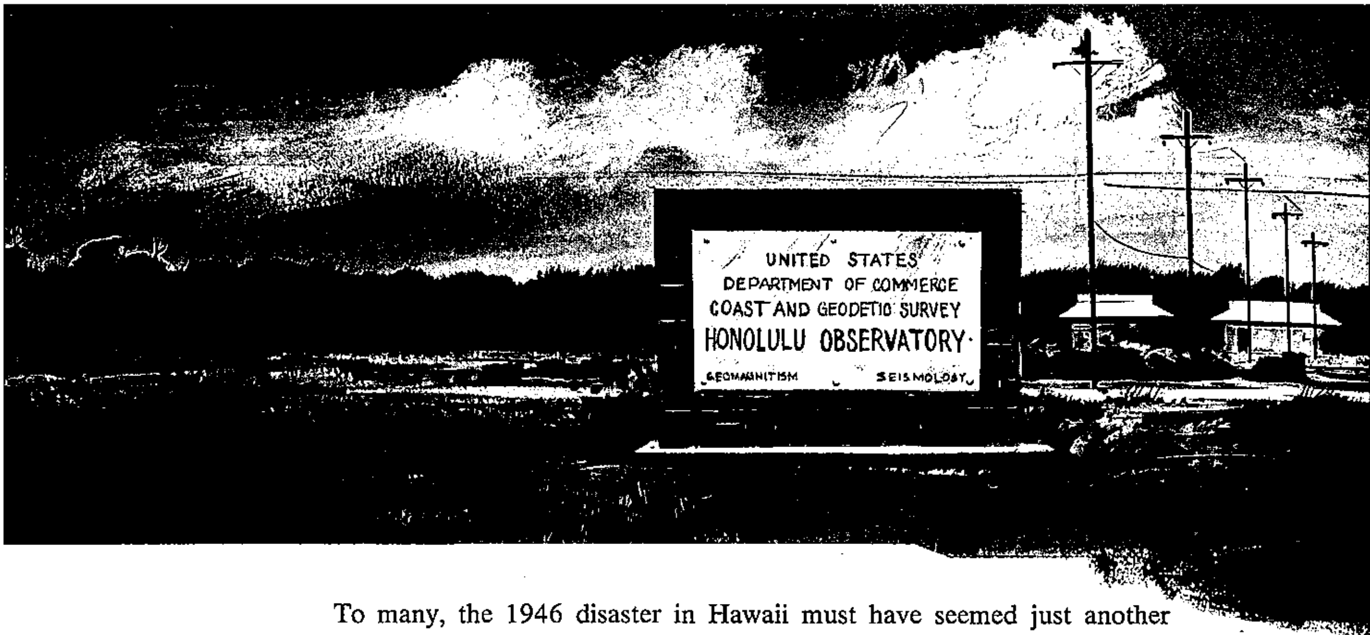
Our understanding of the physics of tsunamis is limited; but our knowledge of their destructive potential is not. Man has lived too long with the great waves. He has seen the rushing wall of water, his fellows drowned, his cities decimated.

In the early morning of April 1, 1946, a violent earthquake disturbed the northern slope of the Aleutian Trench, and triggered one of the most destructive tsunamis in recent years. Minutes after the earthquake occurred, waves more than 100 feet high smashed the lighthouse at Scotch Cap, Unimak Island, killing five.

The first wave struck Hawaii less than five hours later. This wave, and those which followed, battered the islands with waves reaching heights of 55 feet. And when the destructive waves had gone, 159 persons were dead, and 163 injured; 488 homes were demolished, 936 damaged—property damage was estimated at $25 million.

This was the 36th tsunami recorded in Hawaii in 127 years, and the first to do severe damage since 1877; other major tsunamis struck the islands in 1837, and twice in 1868. They came without warning, as the great waves had always come to Pacific Islands.

But the tsunami of April 1946 is distinguished from the rest: it was the worst natural disaster in Hawaii's history; *and the last destructive tsunami to surprise those islands.*



To many, the 1946 disaster in Hawaii must have seemed just another natural tragedy, one of those unavoidable conflicts between man and his planet in which man is so often loser. But, to a group of scientists within the United States Coast and Geodetic Survey, there was nothing inevitable about such loss. Those hundreds of persons killed or injured by the tsunami could have been warned, and saved. Tsunamis, these scientists believed, could be detected and predicted with sufficient reliability to provide early warning to the people of Hawaii.

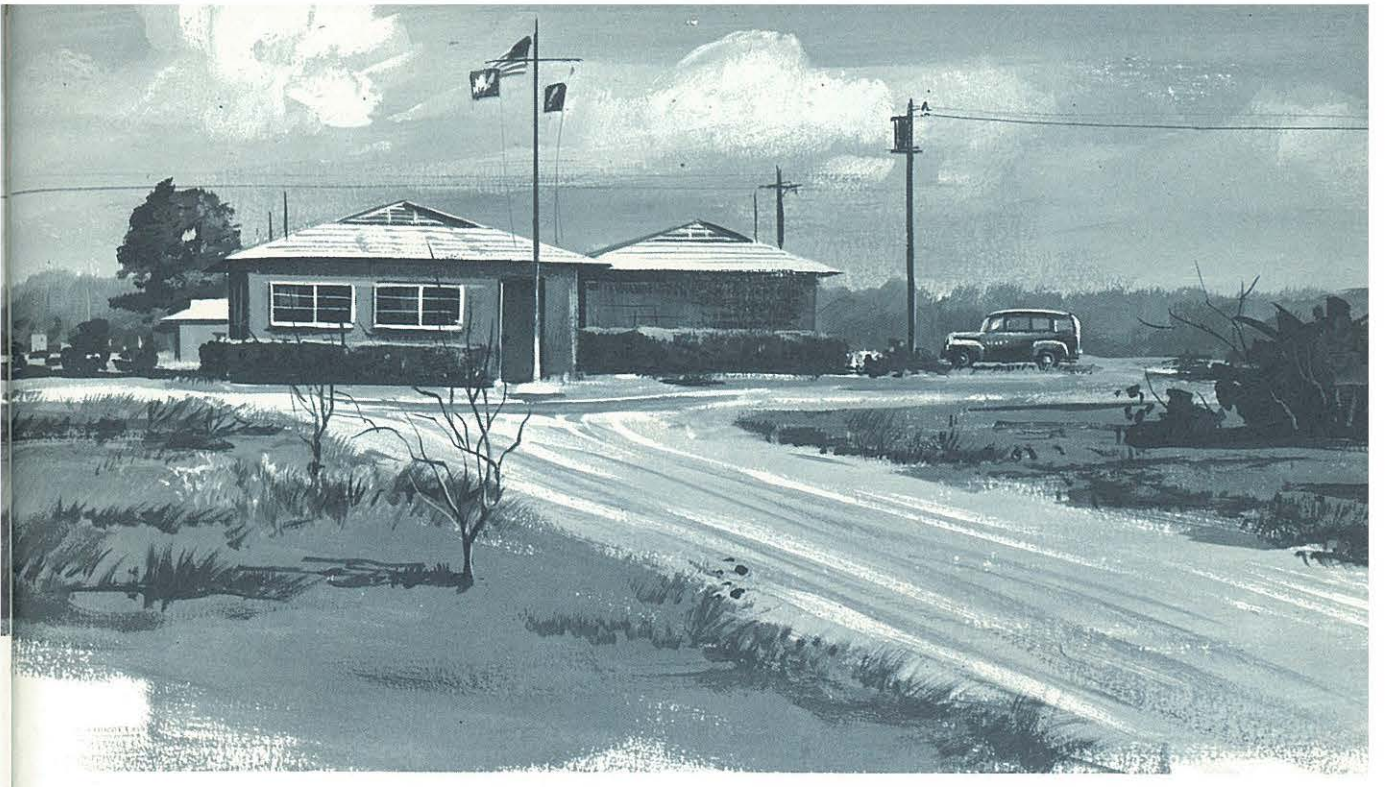
THE SEISMIC SEA-WAVE

The system they envisioned would use seismographs to detect and locate earthquakes, and tide gages to detect passing tsunami waves. These would be linked by an extensive rapid-communications network. But, in 1946, the only available seismographs recorded photographically, and their seismograms were not developed until the following day; tsunamis do not wait for such delays. The coverage of the Coast and Geodetic Survey's network of tide gages was inadequate for this purpose; and no tide-measuring instrumentation existed which could discriminate between tsunamis and other waves. The existing method of determining tsunami traveltime was not sufficiently accurate. And there were no communication circuits suitable for the job at hand.

The tsunami warning system envisioned in 1946 was developed with limited funds and tacit, rather than official, sanction. In two years what had been a wish became a functioning reality.

Studies of existing seismographic instruments narrowed to a new device, which provided a continuous, visible seismic record. Seismographs of this type were constructed and installed in Hawaii and at other points around the Pacific, and equipped with an automatic alarm signal.

Additional tide stations had been installed in the Pacific area, and a seismic sea-wave detector was developed that filtered out tidal and wind-wave motions, recording only those waves which had tsunami characteristics.



SSWWS WARNING SYSTEM

An improved technique for determining tsunami traveltimes was formulated. The construction of probable tsunami paths through concentric plots of equal traveltime, and recalculation of points of equal traveltime along these paths, raised the order of accuracy to approximately 2.3%—about a minute and a half per hour of estimated traveltime. This accuracy can be better or worse, depending only upon the accuracy of bathymetric information along a particular path.

Suitable communications links were established through the facilities of the Civil Aeronautics Administration (now the Federal Aviation Agency) and the military services. Later, the FAA and Defense Communications Agency networks were augmented by the participation of the communications systems of the National Aeronautics and Space Administration and the U. S. Weather Bureau.

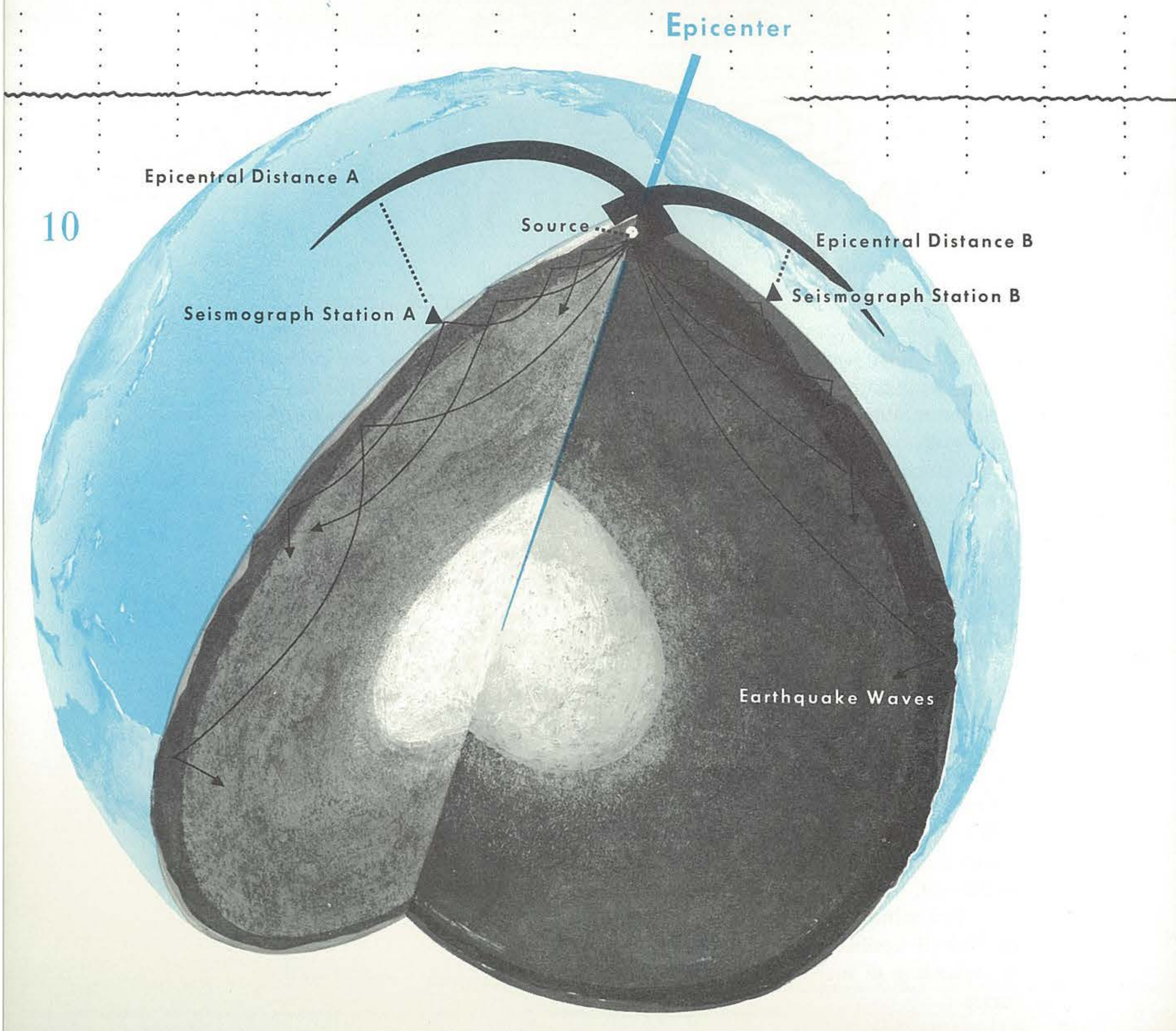
In 1948, the Seismic Sea-Wave Warning System (SSWWS) was put into operation with its headquarters at the U.S. Coast and Geodetic Survey's magnetic and seismological observatory in Honolulu. During the next four years, the SSWWS detected many submarine earthquakes, but no major tsunamis developed, and no full-scale alerts were necessary. It was a time of repeated drills, to keep the system sharp. Then, on November 4, 1952, a submarine earthquake near the Kamchatka Peninsula generated a tsunami felt across the Pacific. The waves caused some $800,000 damage in Hawaii, but they took no lives. The SSWWS had paid its way.

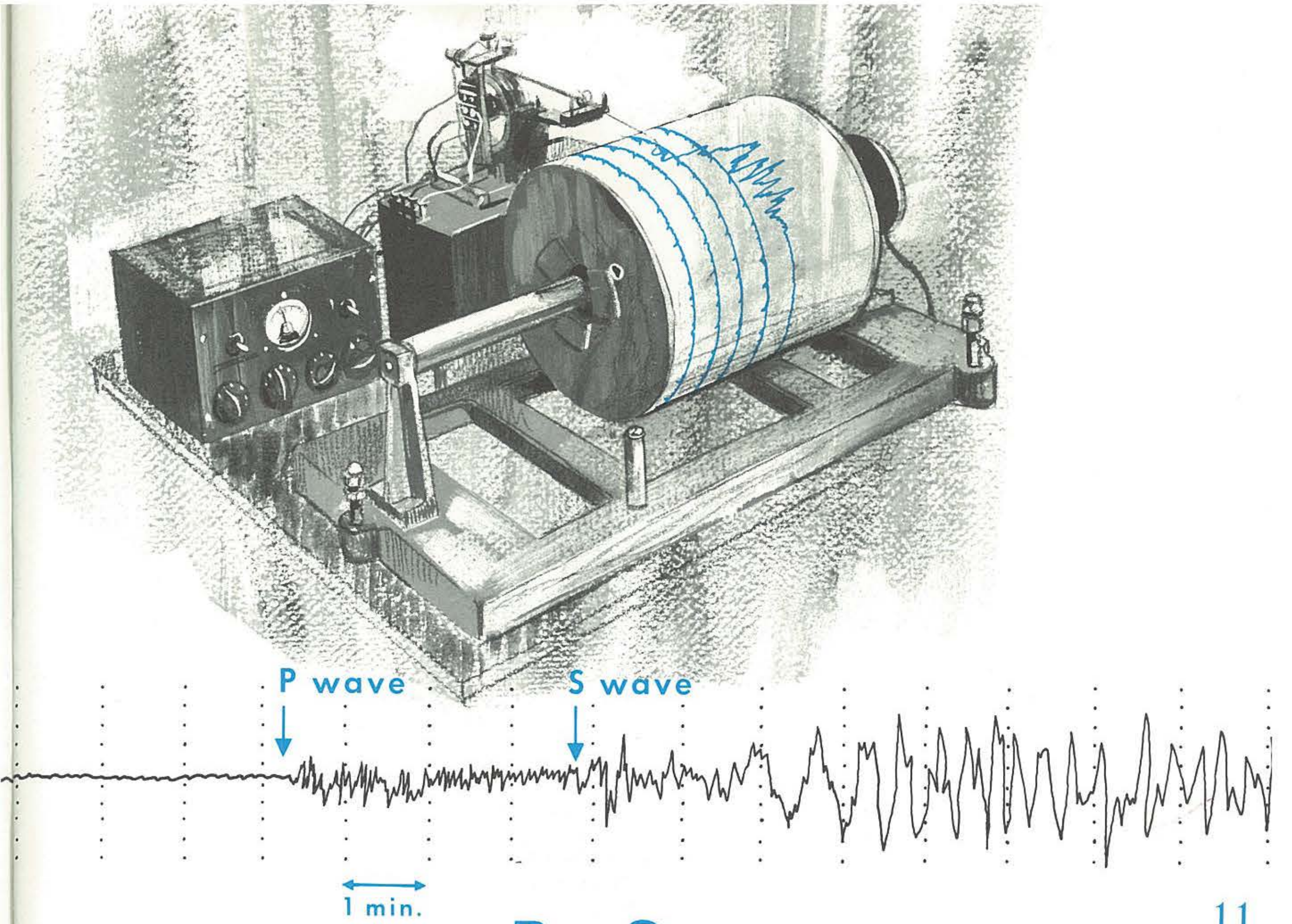
The initial mission of the SSWWS was the protection of the people of Hawaii against the great waves' grim surprises. Today, that mission is expanding to include the early warning of all Pacific nations and territories.

The Honolulu headquarters of the SSWWS is the center of an extensive complex of detectors. At this center, a 24-hour watch is maintained, waiting for the first reactions of instruments thousands of miles away.

Most earthquakes are caused by slippage along strained faults in the earth's crust. The sudden release of energy as these faults slip toward equilibrium produces a variety of earthquake waves, which travel through the earth and across its surface. At seismograph stations, these waves are picked up and translated into electrical signals, which deflect the seismograph's recording arm sufficiently to record the earthquake's "signature." From this signature, or seismogram, seismologists can determine the approximate magnitude of the earthquake, and the surface distance between their seismograph station and the source of the disturbance.

The first line of detection for the SSWWS is a network of seismograph stations. Some of these are operated domestically by the Coast and Geodetic Survey and by private institutions; others are private or governmental seismological observatories in cooperating Pacific nations. The occurrence of an earthquake of sufficient magnitude to generate a tsunami alerts each seismograph station equipped with an automatic seismic alarm.

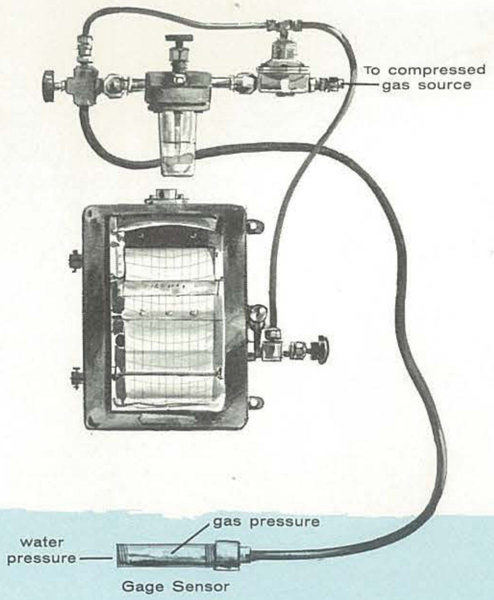




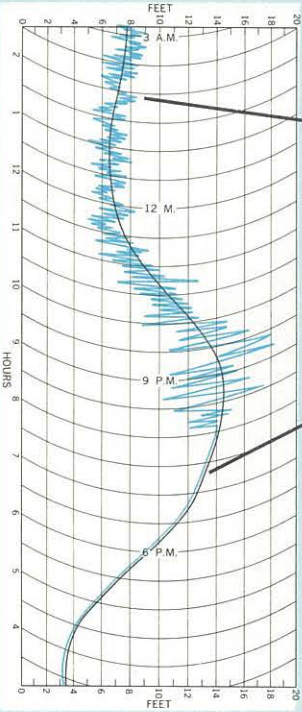
The difference between P and S wave arrival time at each Seismograph Station can be used to calculate the distance between the source and the seismograph locations. Arcs of surface distance intersect at the earthquake epicenter.

The system responds immediately. Participating seismograph stations report the local arrival time of P (longitudinal, compression) and S (transverse, shear) earthquake waves. Because the propagative characteristics of earthquake waves are well-established, the time interval between P and S wave arrival can be used to compute the surface distance between each seismograph station and the source of the disturbance; the intersection of these arcs of distance is the earthquake epicenter—the point on the earth's surface above the subterranean source, or focus, of the earthquake. If this point falls on or near the ocean, or if an earthquake occurring inland has sufficient intensity to cause extensive deformation of the ocean floor, tsunami generation is possible.

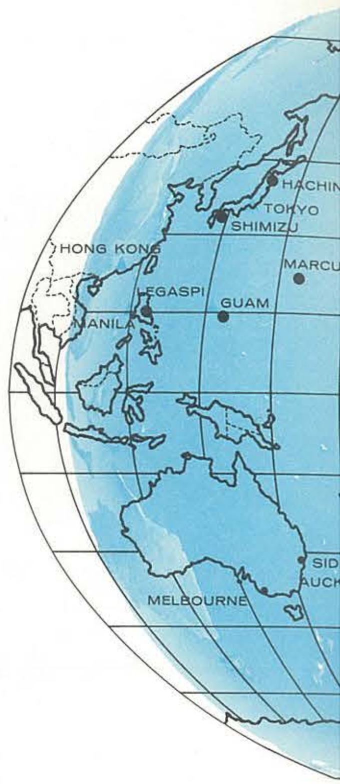
On the basis of seismographic evidence, Honolulu Observatory issues an advisory bulletin, which tells SSWWS participants that an earthquake has occurred, and where; and that the possibility of tsunami generation exists. Estimated time of arrival (ETA) is provided for each SSWWS participant's location.



Height of water above gage sensor is indicated by amount of gas pressure required to equalize water pressure.



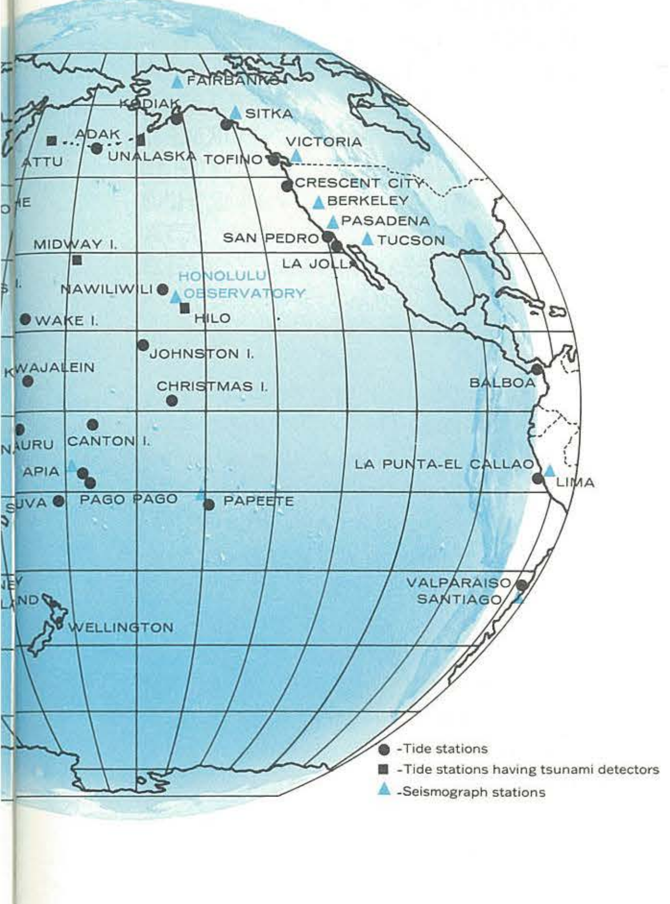
Tsunamis appear on the tide gage records--or marigrams--as distinct abnormalities. Marigrams are usually the first positive evidence that an earthquake has generated a tsunami.



Now the SSWWS turns to its second line of detection: the network of tide stations. At these stations, gages record the cycle of the tides continuously. Passing tsunamis appear on the tidal record, or marigram, as distinctive abnormalities. Where tidal variations are small, seismic sea-wave detectors have been installed; these record only those passing waves which have the characteristics of tsunamis. With the occurrence of a major earthquake, SSWWS headquarters requests tide observers closest to the epicenter to check their record for "unusual activity."

The first positive indication of the existence of a tsunami usually comes from tide stations nearest the disturbance. When confirmation is received, Honolulu Observatory issues its warning, alerting SSWWS participants to the approach of a potentially destructive seismic sea-wave and repeating tsunami ETA's for all locations. Local warning, evacuation, and other emergency procedures are then undertaken by the designated agents of SSWWS participants, as they attempt to prevent loss of life and reduce loss of property during the tsunami emergency.

A tsunami emergency does not end until the waves have crossed the Pacific; sometimes this crossing leaves a wake of death and destruction, sometimes it does not. But, to the SSWWS crew, the end of one emergency means a return to the work of waiting, and of watching. For when nature is the enemy of man, she strikes quickly, unpredictably, and with awesome force.



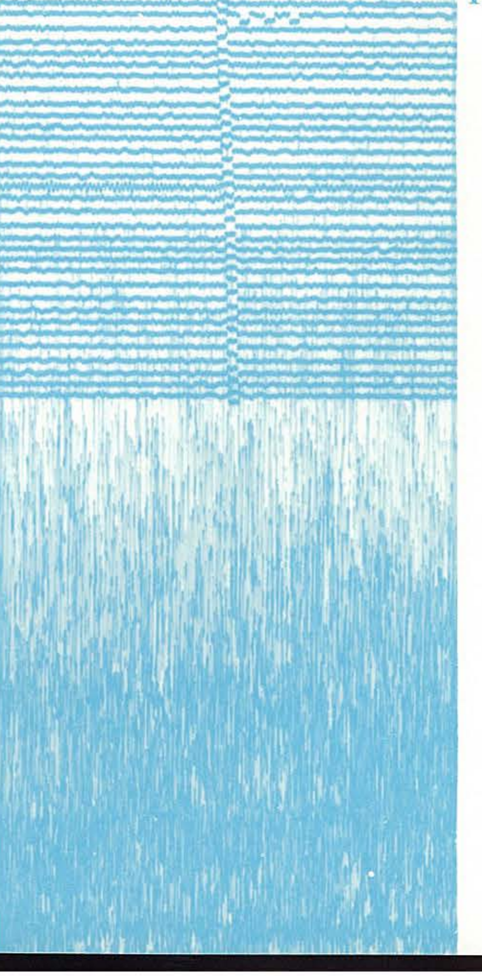
Until 1964, three major tsunamis had crossed our largest ocean since the Kamchatka tsunami of 1952. The Aleutian tsunami of March 9, 1957 caused damage in the Aleutians, Hawaii, Japan, and along the west coast of North America, but no lives were lost.

The Chilean tsunami of May 1960 was the most destructive in recent history, causing deaths and extensive damage in Chile, Hawaii, the Philippines, Okinawa, and Japan. Waves 15-35 feet high pounded the Hawaiian city of Hilo, leaving 61 dead and causing $22 million property damage. The tsunami arrived six hours after a warning had been issued to the public, and only those who ignored the warning were taken by the waves. In Japan, no general tsunami alert was issued, for it was not known that a tsunami of such distant origin could be destructive. The waves left at least 180 persons dead or missing in northern Japan and Okinawa, 20 dead in the Philippines, caused $500,000 damage along the western coast of the United States, and did considerable damage in New Zealand. All Chilean coastal towns between the 36th and 44th parallels were destroyed or severely damaged.

The Peruvian tsunami of November 20, 1960 caused 11 deaths on nearby coasts but did little damage in other Pacific areas.

March 28, 1964

At 03:36:13 Greenwich Mean Time, an earthquake strikes the northern shore of Prince William Sound, Alaska. This disturbance, at 8.5 on the Pasadena scale of earthquake magnitude, is the most severe ever recorded for North America; and in Alaska, where it is still Good Friday afternoon, the earthquake is the most ironic. It will be called the Good Friday Earthquake by the press; science will call this great initial shock, and its hundreds of after-shocks, the Prince William Sound Earthquakes of 1964.



The warning alarm sounds at Honolulu Observatory, and at four other participating seismograph stations. The SSWWS begins its race with time.

0344* Seismic sea-wave warning alarm sounds at the Honolulu Observatory. Requests issued for immediate readings from seismograph stations at College, Alaska; Sitka; Pasadena; Berkeley; Tucson; Tokyo; and Guam.

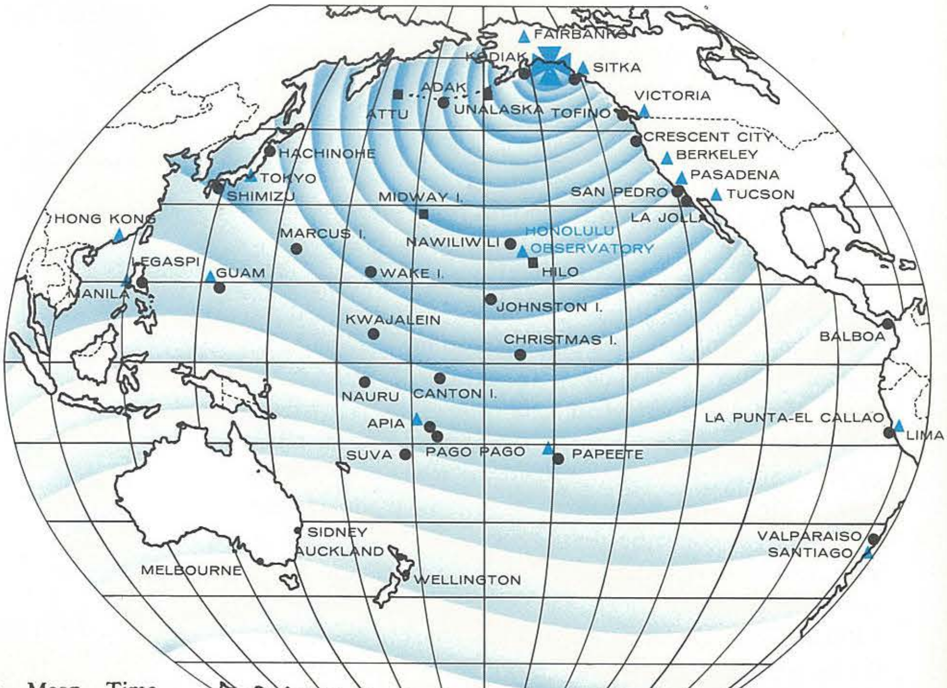
0452 Honolulu Observatory completes preliminary determination of location of earthquake epicenter: 61 N., 147.5 W.

0502 Honolulu Observatory issues first advisory via FAA and Defense Communications network:

THIS IS A TIDAL WAVE ADVISORY. A SEVERE EARTHQUAKE HAS OCCURRED AT LAT. 61 N., LONG. 147.5 W., VICINITY OF SEWARD, ALASKA, AT 0336Z, 28 MAR. IT IS NOT KNOWN, REPEAT NOT KNOWN, AT THIS TIME THAT A SEA WAVE HAS BEEN GENERATED. YOU WILL BE KEPT INFORMED AS FURTHER INFORMATION IS AVAILABLE. IF A WAVE HAS BEEN GENERATED, ITS ETA FOR THE HAWAIIAN ISLANDS (HONOLULU) IS 0900Z, 28 MARCH . . .

0530 Communications inoperative on Alaskan mainland. Honolulu Observatory issues second bulletin; this is an information bulletin, stating that it is not yet known whether a seismic seawave has been generated, but providing all participants in the SSWWS with estimated times of arrival.

The observatory also requests inspection of tide records by observers at Unalaska, Kodiak, Adak, Sitka, Alaska; and Crescent City, California.



* References are to Greenwich Mean Time (GMT), or ZULU, as the "Z" in teletype messages indicates. Pacific Standard Time (which includes Alaska panhandle) is 8 hours behind GMT; Yukon Time (Yakutat north), 9; Alaska Time (most of central Alaska) and Hawaiian Standard Time, 10; and Bering Time, 11.

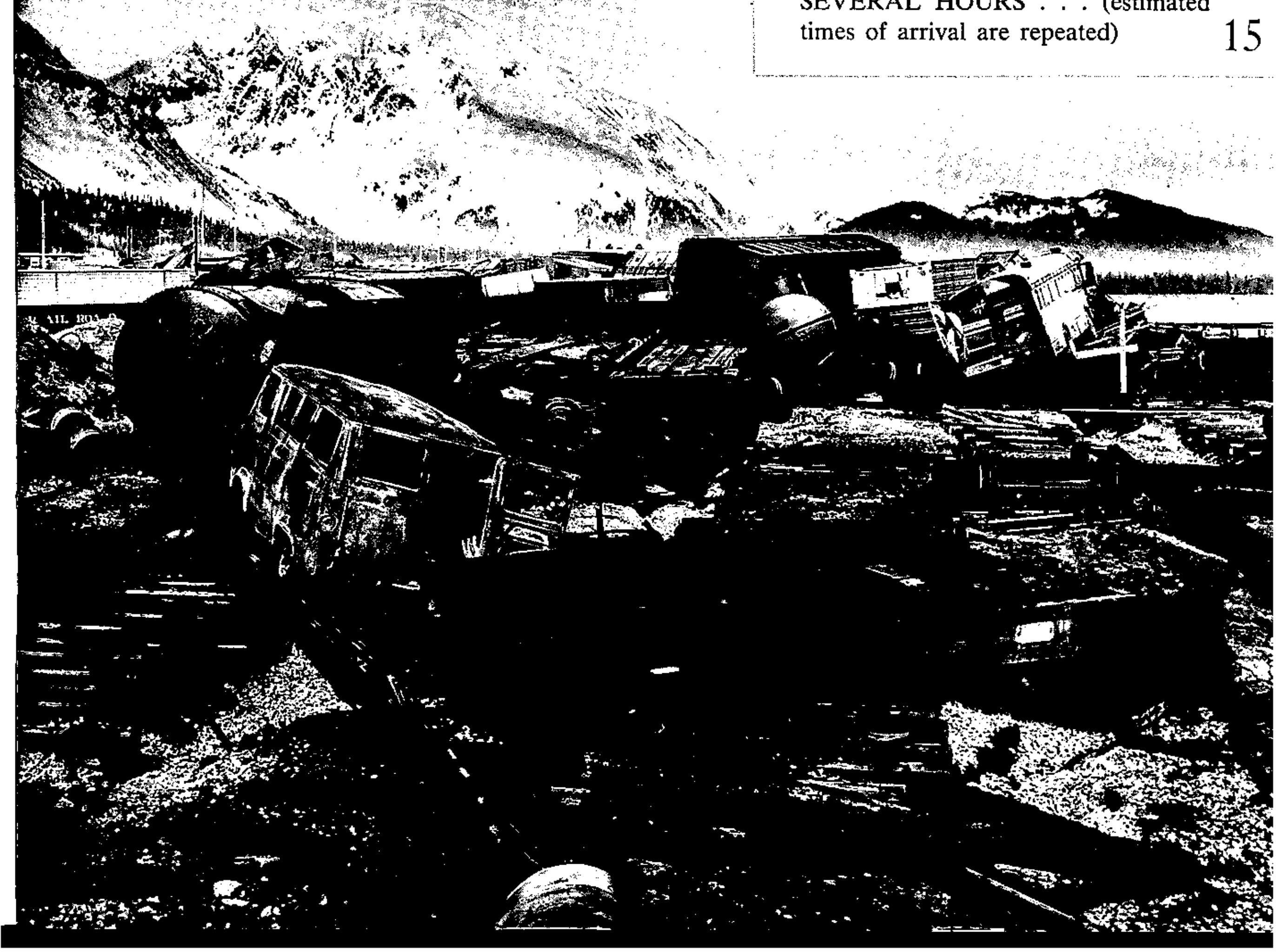
0555 Kodiak replies:

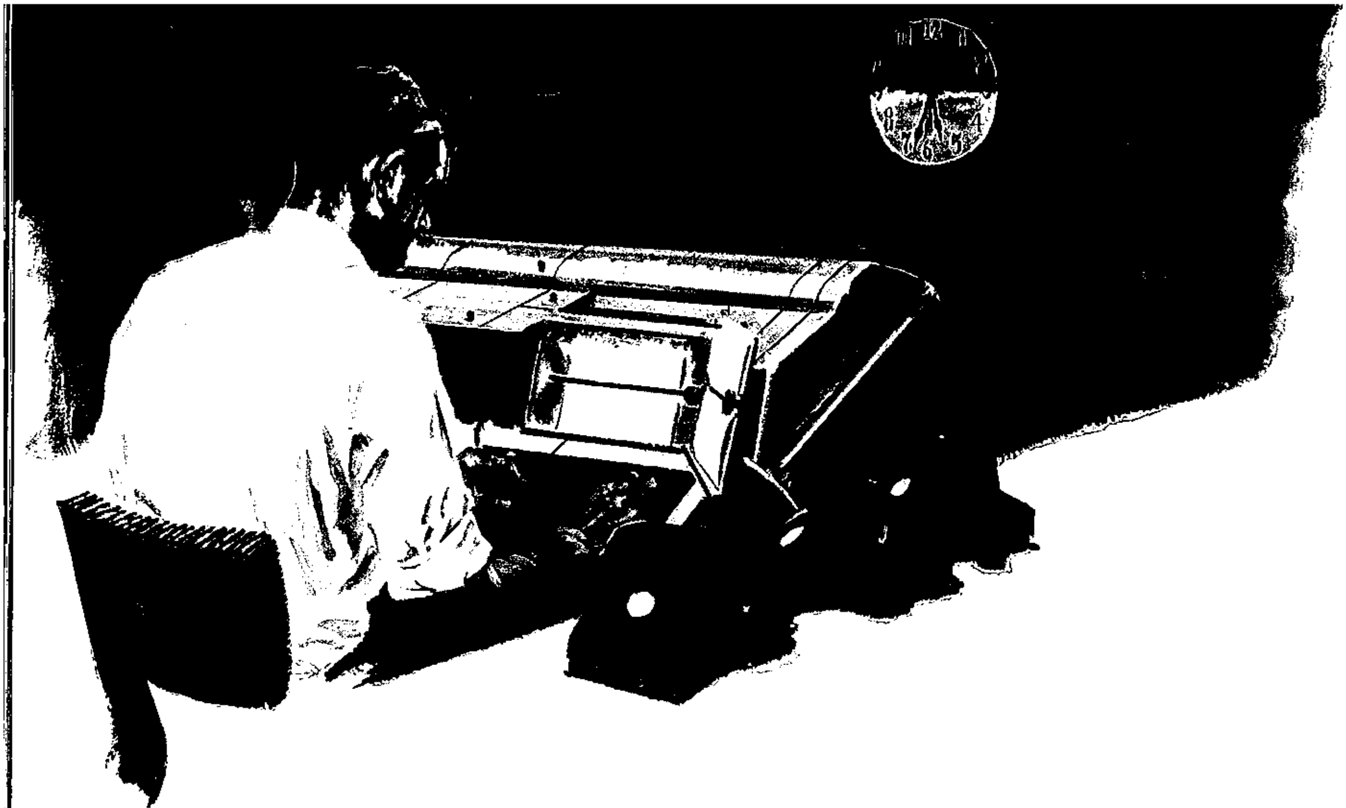
EXPERIENCE SEISMIC SEA-WAVE AT 0435Z. WATER LEVEL 10-12 FT ABOVE MEAN SEA LEVEL. WILL ADVISE.

0630 Another message from Kodiak tide observer confirms existence of seismic sea-wave.

Honolulu Observatory issues third bulletin:

THIS IS A TIDAL WAVE/SEISMIC SEA-WAVE WARNING. A SEVERE EARTHQUAKE HAS OCCURRED AT LAT. 61 N., LONG. 147.5 W., VICINITY OF SEWARD, ALASKA, AT 0336Z, 28 MAR. A SEA WAVE HAS BEEN GENERATED WHICH IS SPREADING OVER THE PACIFIC OCEAN. THE ETA OF THE FIRST WAVE AT OAHU IS 0900Z, 28 MARCH. THE INTENSITY CANNOT, REPEAT, CANNOT BE PREDICTED. HOWEVER, THIS WAVE COULD CAUSE GREAT DAMAGE IN THE HAWAIIAN ISLANDS AND ELSEWHERE IN THE PACIFIC AREA. THE DANGER MAY LAST FOR SEVERAL HOURS . . . (estimated times of arrival are repeated)





0700 Tsunami reaches Tofino, B. C.

0708 Kodiak reports series of waves:

SEA WAVES AT 0435Z; 32 FT AT 0540Z; 35 FT AT 0630Z; 30 FT SEAS DIMINISHING, WATER RECEDING. EXPECT 6 MORE WAVES.

0739 First wave arrives at Crescent City. The wave is 3 feet high. Some evacuees return to danger area.

0750+ Four persons drown at DePoe Bay, Oregon.

0900 Tsunami reaches Hawaiian Islands. Damage slight at Hilo, with three restaurants and a house inundated; at Kahului, a shopping center is flooded.

0920 A 12-foot wave—probably the fourth—sweeps into Crescent City. This wave, and its successors, destroy or displace more than 300 buildings; five bulk gasoline storage tanks explode; 27 blocks are substantially destroyed; there are casualties.

1020 Tsunami reaches east coast of Hokkaido, Japan.

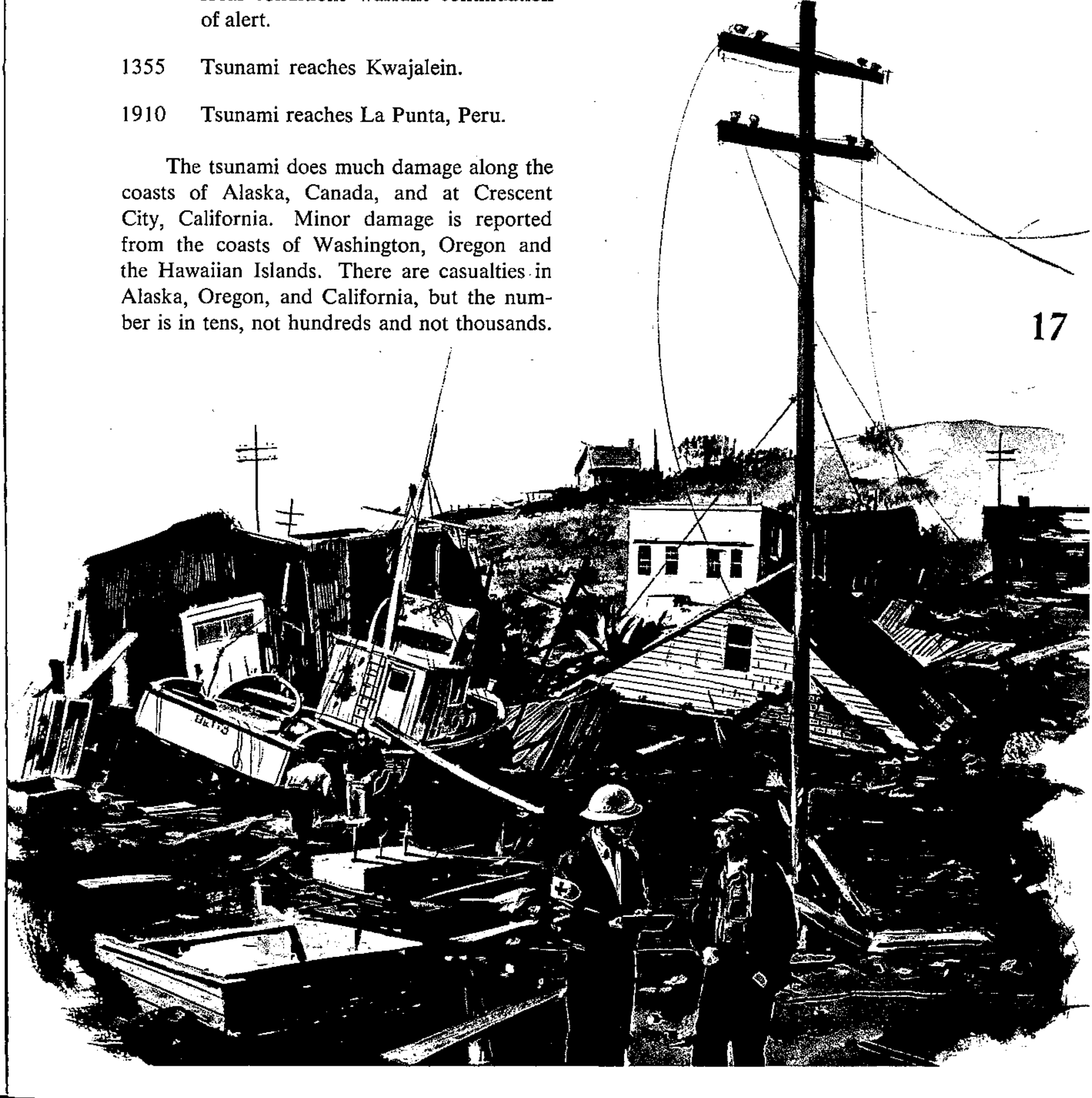
1038 Tsunami reaches northeast coast of Honshu, Japan.

1100 Honolulu Observatory sends final bulletin. It is an all-clear for Hawaii; other participants in the SSWWS are advised to assume all-clear status two hours after their tsunami ETA unless local conditions warrant continuation of alert.

1355 Tsunami reaches Kwajalein.

1910 Tsunami reaches La Punta, Peru.

The tsunami does much damage along the coasts of Alaska, Canada, and at Crescent City, California. Minor damage is reported from the coasts of Washington, Oregon and the Hawaiian Islands. There are casualties in Alaska, Oregon, and California, but the number is in tens, not hundreds and not thousands.



And when the great waves finally touch your town . . .

Call it two-thirty in the morning, any Sunday. Most of your town is asleep. Few lights show, and on the coastal highway the stream of cars has thinned and the traffic signals are set to flash their amber warning all night long. It is quiet. Now and then there comes a roar from the highway, or the humming of distant aircraft. And on these sounds, and on the greater silence, there is the perpetual stirring of the ocean as it strokes the beach, and moves the ships at harbor and the timbers of their piers.

The earth, like the sea, is ever-changing. Now, southwest of Kodiak, Alaska, a process that began centuries ago nears its inevitable, catastrophic end. The constant circulations and alterations of the earth's interior produce tremendous strains along its brittle crust. The strains in a block of crustal material the size of California have reached a critical point; like a longbow pulled too far, the block can be strained no further—in a moment it must yield along its lines of weakest structure.

The accumulated strain is concentrated along a fault, or fracture, which runs through the block, held in a strained position by a supporting structure of stronger material. Strain increases, the supporting rocks slip and rupture, and each side of the divided block returns toward equilibrium. The strain energy is released as heat, and sound, and in the form of earthquake waves, which vibrate through the earth, and over its surface. The initial fracture occurs 20 miles below the surface of the earth, but its effects are manifest along the ocean floor; for in that unknown, underwater world 15,000 feet down, a gigantic block of crustal material has thrust 50 feet vertically, and disturbed an ocean.

who will warn you, and how?

Seven minutes later the first ground vibrations trigger the automatic alarm at Honolulu Observatory. It is a jarring, brazen noise in this place of silence—the normal sounds are the hum and click of instruments and their computers, and the wind, and the sea off Barbers Point. The SSWWS crew begins the analytical work preliminary to advice or warning. Their seismograms tell them the approximate magnitude of the disturbance, and the distance from their station to the epicenter. Other distance computations arrive from Berkeley, Tokyo, and Fairbanks. The epicenter is in an oceanic area; magnitude is 8.3, more than sufficient for tsunami generation. Before the earthquake is an hour old, the SSWWS issues its advisory message, and, via telephone, alerts the cognizant officials in Hawaii. An hour later the Kodiak tide observer reports unusual activity. A tsunami warning is sent to all participants.

The tsunami's estimated time of arrival in your town is 7:30. At 4:40, the tsunami warning is relayed to your sheriff, police chief, and chief of county Civil Defense. They have less than three hours to implement their plan for your survival. The decisions they make between now and the arrival of the tsunami will determine whether lives are lost in your town on this Sunday morning. The tsunami may arrive at your town as a 3-foot wave, or a scarçely detectable surge; or it may crush your town under tons of rushing water. These men must assume a maximum of danger for you, and for your city. If nothing happens, if the tsunami spares your coast, they will be subject to some criticism; that is an occupational hazard of all who deal in protection of life and property—but one cannot gamble what he cannot afford to lose.

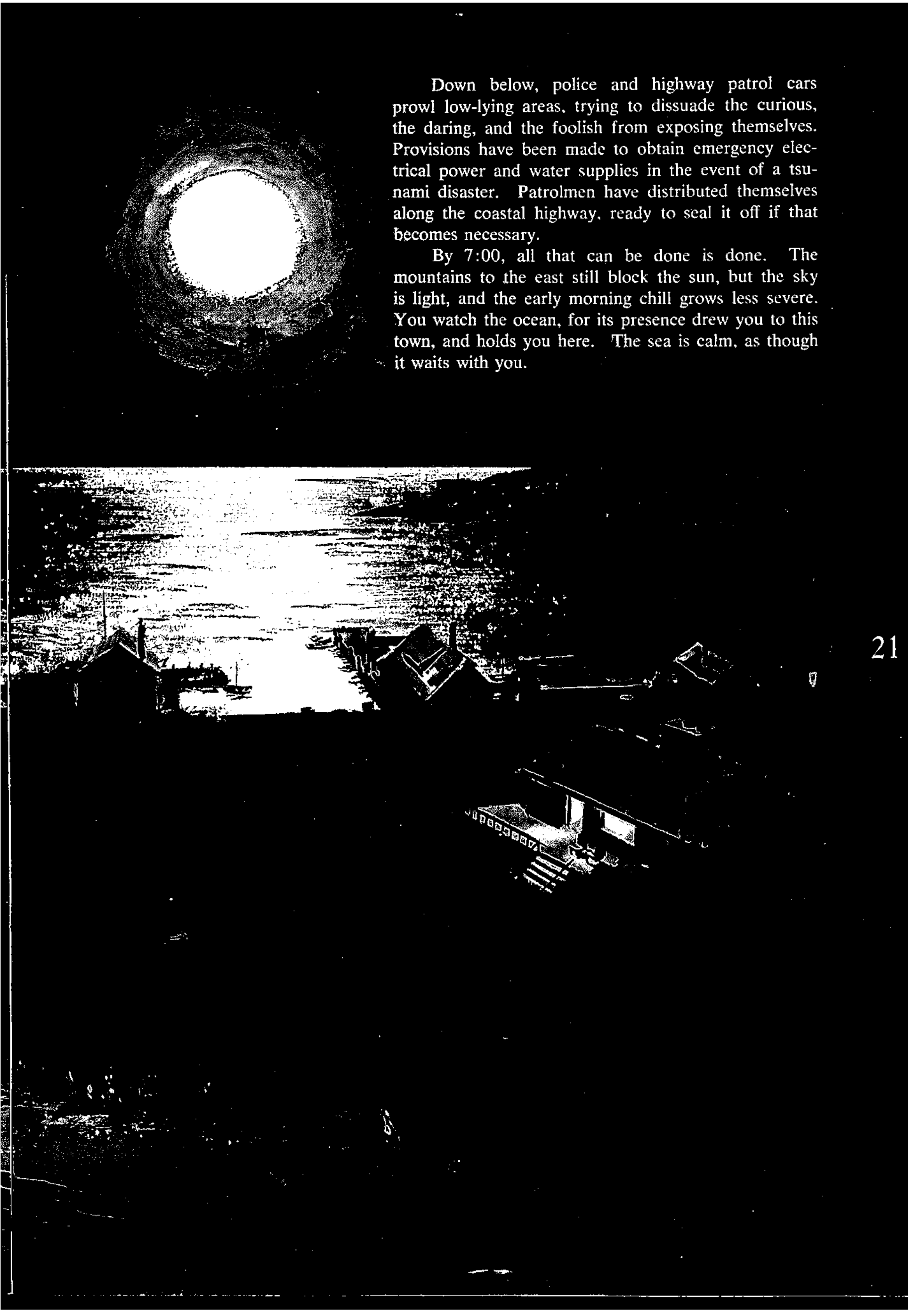
Evacuation of persons in low-lying coastal areas and around the rims of bays and harbors is essential, for these are consistently the hardest hit by tsunamis. As police and Civil Defense personnel are mobilized, the evacuation begins. It is too early in the morning for radio or television to do much good. Nevertheless, all-night stations throughout your state broadcast the warning at intervals; the one or two or dozen persons who hear them may be saved. Loudspeaker trucks deploy along the shoreline, and lights come on as your town wakes up.

It is not as simple as it seems. At five in the morning, on Sunday, people are reluctant to be evacuated, and skeptical of "tidal wave" talk. Emergency workers must go from door to door, explaining the dangers, the risks, the fearsome possibilities. Some choose to remain at home. Others cooperate.

And time is running out.

Ships must be moved to deep water, where they will be safe from the waves of the tsunami. With the cooperation of the port authority, those with crews aboard respond quickly. By 6:00, ships and small craft are moving out of the bay. Some, unmanned, remain at their moorings. They cannot be helped.

On the hill overlooking the bay, a huddled group of sleepy, disgruntled people stir restlessly. Some sit in cars. Others stand along the seaward cliff. They are the first evacuees, and their number grows.



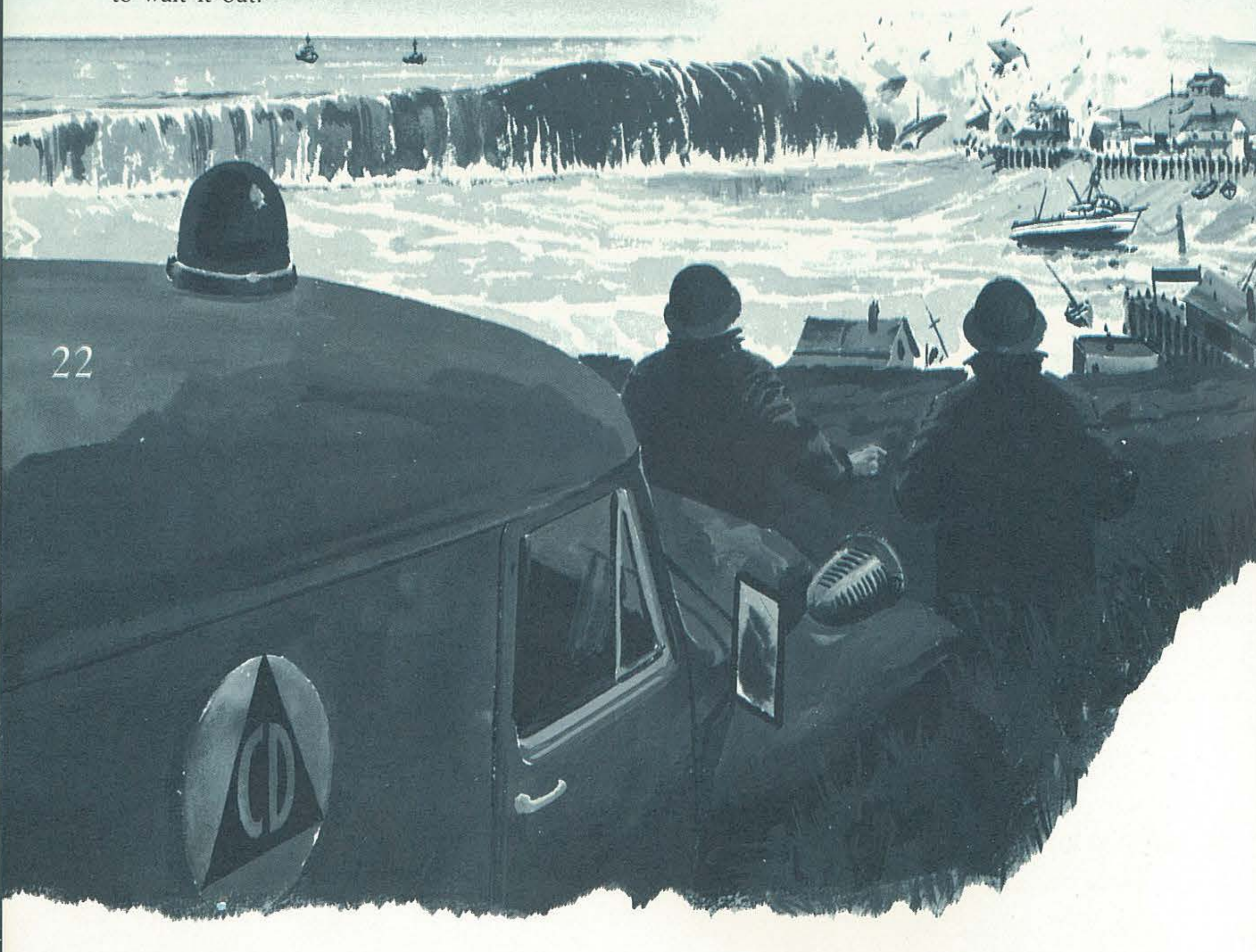
Down below, police and highway patrol cars prowl low-lying areas, trying to dissuade the curious, the daring, and the foolish from exposing themselves. Provisions have been made to obtain emergency electrical power and water supplies in the event of a tsunami disaster. Patrolmen have distributed themselves along the coastal highway, ready to seal it off if that becomes necessary.

By 7:00, all that can be done is done. The mountains to the east still block the sun, but the sky is light, and the early morning chill grows less severe. You watch the ocean, for its presence drew you to this town, and holds you here. The sea is calm, as though it waits with you.

Nothing happens until about 7:20. Then, for a few minutes, the waterline advances up the beach and recedes, like a tide in miniature. You cannot see the movement from where you stand; it is too gradual, and too far away. This is the first wave of today's tsunami.

The second wave arrives at 7:35, the waterline moving farther up the sand before draining back to sea. As with the first wave, the rise and fall of sea level is too small, and too gradual, to be noticed from the evacuation area.

To you, and to the other evacuees, nothing has happened, and it is a quarter to eight. It seems that the emergency has come to nothing but inconvenience on this Sunday morning, and there is a kind of angry relief, and the beginning of temper. You hear someone say he's going home. People move away. Police and Civil Defense people try to get everyone to wait a little longer, but no one seems willing to give them the benefit of the doubt. And you think, "Well, why not?" It is 7:55, nothing has happened. You're unhappy about being routed out of bed to stand on this cold hill and watch for . . . . nothing. But something holds you. You decide to wait it out.



Then you notice the change. The second wave's run-off has continued and the ocean floor is exposed almost to the mouth of the bay. You can see the turbulent water in the distance, where, as though meeting the ocean's very edge, a churning wall of water more than fifty feet high enters the bay. Great rocks ripped from the ocean floor are rolled before it, and, as the wave advances, you hear its hissing sound—like a locomotive letting off steam. Behind the wave front, the ocean is flat and serene, and the ships hove-to on the horizon feel little movement of the water.

This is the great wave, the tsunami. You have never seen a natural force more menacing than this, or so inexorable. For the first time since the evacuation, you feel the beginning of a general kind of fear—the fear man has when he sees nature with her mask torn away.

You could be watching a slow-motion film. The wave approaches at about 30 miles per hour, but its size makes it seem infinitely slower. The beach gradually disappears beneath the steep front, which reaches a critical inbalance and crashes forward in a powerful surge. As the great mass of water drives forward, the lines of beach houses are ripped from their foundations and splintered, and the palms and eucalyptus trees which decorate your streets are uprooted and destroyed. The water sweeps this debris against other structures, and, as though it were a sugar model, the downtown section sinks into the flood. Cars are swept about like plastic bath-tub toys, and stacked, smashed and drowned, against buildings and at the ends of flooded streets. The railroad's rolling stock is torn and pushed to destruction by the wave, and those buildings which stand are gutted. Fishing boats and small craft are sunk or driven inland on the wave. Toward the edge of town, oil storage tanks are knocked off their foundations, and, somehow ignited, leak flaming fuel. The wave carries the flames through town, destroying with fire that which the water does not.

Nine waves strike your town in all. The third and fourth waves are the worst, and the seventh does some damage. Part of your town is burning, part of it is gone. Seven people are missing and presumed drowned, two are injured. They had been evacuated, but had returned before the third wave. It is not yet ten o'clock.

The loss numbs and bewilders you. It has been too swift, and somehow too specific. You wonder why the great waves took *your* town, and how you can recover; for a moment, it seems useless to go on. But you look around and see the people who share your loss as they have shared your vigil, and it comes to you: *What if we had not been warned?* How many, of the hundreds with you now, would have survived this day?

The great waves cannot be stopped, but they can be cheated. They have been cheated today. The people of your town persist—and with help, they will rebuild—it is a tradition of the species.

REMINDERS

The warning and evacuation of personnel in endangered areas is the job of designated agents participating in the SSWWS. The agent in your location will know what measures to take—and will take them, with your cooperation. You can help him, and yourself, by remembering these facts:

1. All earthquakes do not cause tsunamis, but many do; when you hear that an earthquake has occurred in the Pacific Ocean area, stand by for possible communications from your local emergency headquarters.
2. An earthquake in your immediate area should be interpreted as a natural seismic sea-wave warning; do not stay in low-lying coastal areas after a local earthquake has occurred.
3. A tsunami is not a single wave, but a series of waves. If you have been evacuated as a result of a SSWWS warning, stay out of the danger area until the entire wave-series has passed.
4. Approaching tsunamis are sometimes heralded by a noticeable rising or falling of coastal ocean water. This is nature's seismic sea-wave warning; it should be heeded by those in low-lying coastal areas.
5. There is at present no way to determine in advance the amplitude, or size, of tsunamis in specific locations. A small tsunami at one beach can be a giant a few miles away; don't let the modest size of one make you lose respect for all.
6. The SSWWS does not issue false alarms. When a warning is issued, a seismic sea-wave exists. The tsunami of May 1960 killed 61 persons in Hilo, Hawaii, who thought it was "just another false alarm."
7. All tsunamis—like hurricanes—are potentially dangerous, even though they may not strike each Pacific coastline or do damage at each coastline they strike.

8. Never go down to the beach to watch for a tsunami; when you can see the wave you are too close to escape it.
9. Sooner or later, tsunamis visit every coastline in the Pacific. This means that SSWWS warnings apply to you if you live in *any* Pacific coastal area.
10. During a tsunami emergency, your local Civil Defense, police, and other disaster organizations will try to save your life. Give them your fullest cooperation.

Make a point of learning these important facts, and

WRITE THEM DOWN:

Source of official evacuation advice:____________________

Height of your street above sea level:____________________

Distance of your street from coast:____________________

Location of safe area:____________________

Evacuation route:____________________

- Unless otherwise determined by competent scientists:

potential danger areas are those less than 50 feet above sea level and within one mile of the coast for tunamis of distant origin.
potential danger areas are those less than 100 feet above sea level and within one mile of the coast for tunamis of local origin.

Stay tuned to your radio or television stations during a tsunami emergency–SSWWS bulletins issued through Civil Defense and the Weather Bureau can help you save your life!

SSWWS

ORGANIZATION AND COMMUNICATIONS

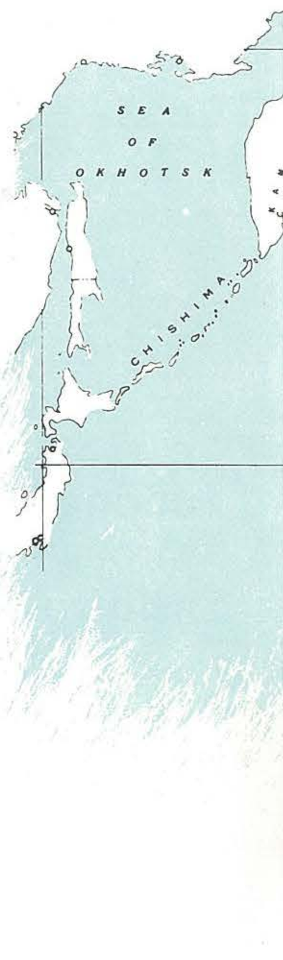
The operation of the SSWWS involves coordination of activities at several administrative and governmental levels, and a complex range of individual responsibilities. First, SSWWS participants must be warned; second, recipients of tsunami warnings must disseminate them within their areas of responsibility; and, finally, those responsible at the local level must act in response to the anticipated danger.

The U.S. Coast and Geodetic Survey has the responsibility of warning those agents designated by each SSWWS participant that a potentially dangerous tsunami exists, and to advise those agents of the first wave's estimated time of arrival in their areas. Because speed is the essential characteristic of any warning system, the SSWWS must limit the number of its transmissions to a single warning point in a country, territory, or state.

Participants in the SSWWS must meet several requirements. First, the central governmental or administrative head of an affected area must establish a single point of reception for SSWWS warnings. Then, to ensure the speedy dissemination of these warnings, SSWWS participants must develop techniques and equipment which ensure the speedy dissemination of tsunami warnings within their areas of responsibility. The internal dissemination of SSWWS messages from the initial recipient to the general populace is submitted in outline form to the U. S. Coast and Geodetic Survey for recommendations and approval; this outline must contain the names or offices of responsible administrators at both central and local levels, the means of communication used, and the operational program as it would function during a tsunami emergency. Foreign participants are expected to arrange their own systems of communication, for use in combination with the nearest United States communications facility as designated by the U. S. Coast and Geodetic Survey.

All SSWWS members, at all levels of participation, are understood to have the continuing responsibility of educating the public to the dangers of seismic sea-waves. They are also expected to develop safety measures which prevent loss of life and reduce property damage.

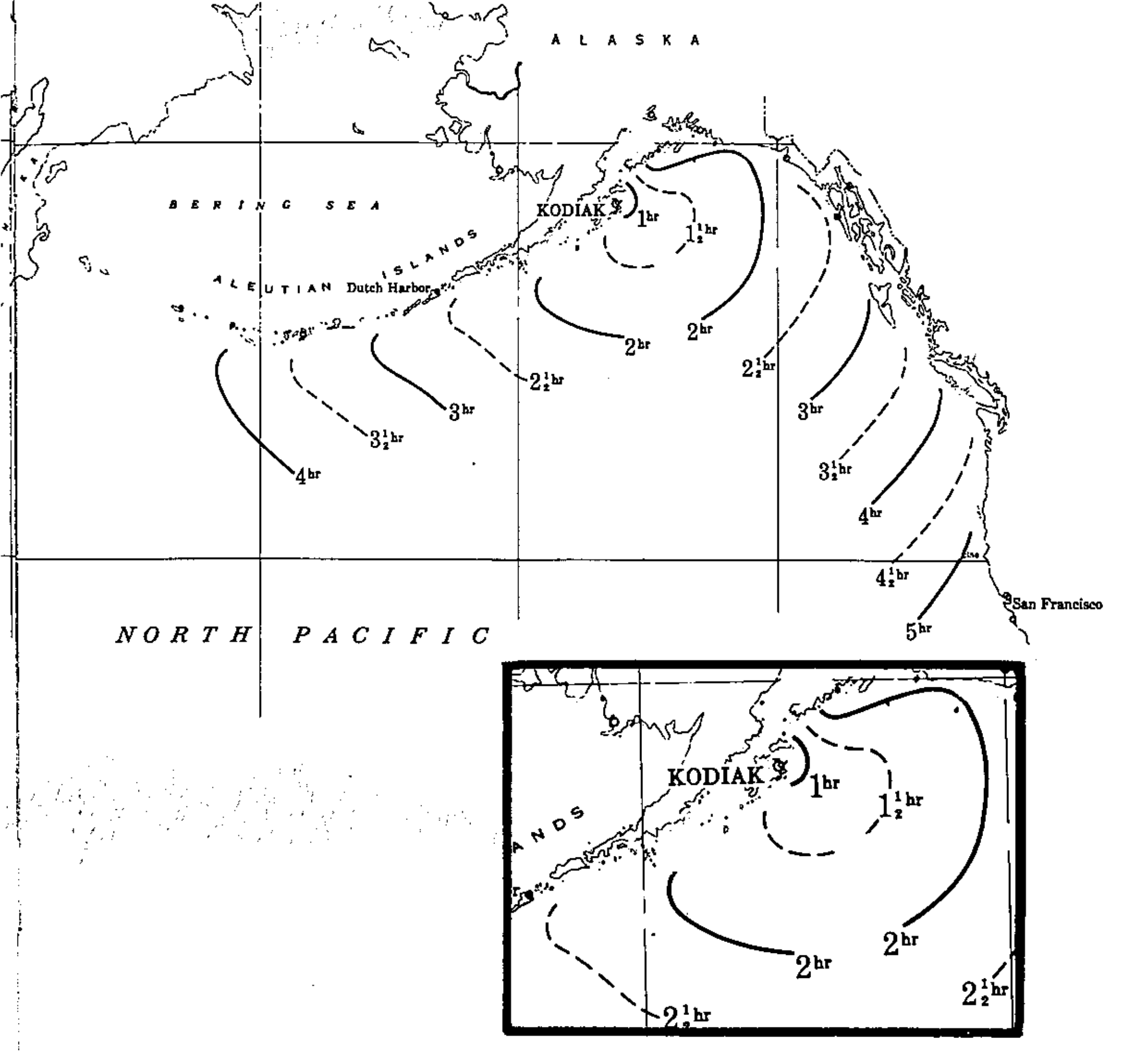
At present, the SSWWS serves the United States and American Samoa; Canada; Chile; the Fiji Islands; French Polynesia; Hong Kong; Japan; New Zealand; the Republic of the Philippines; Taiwan; and Western Samoa. The communications links between Honolulu Observatory and these SSWWS members, and the internal organization and dissemination channels of each, are summarized below.



UNITED STATES

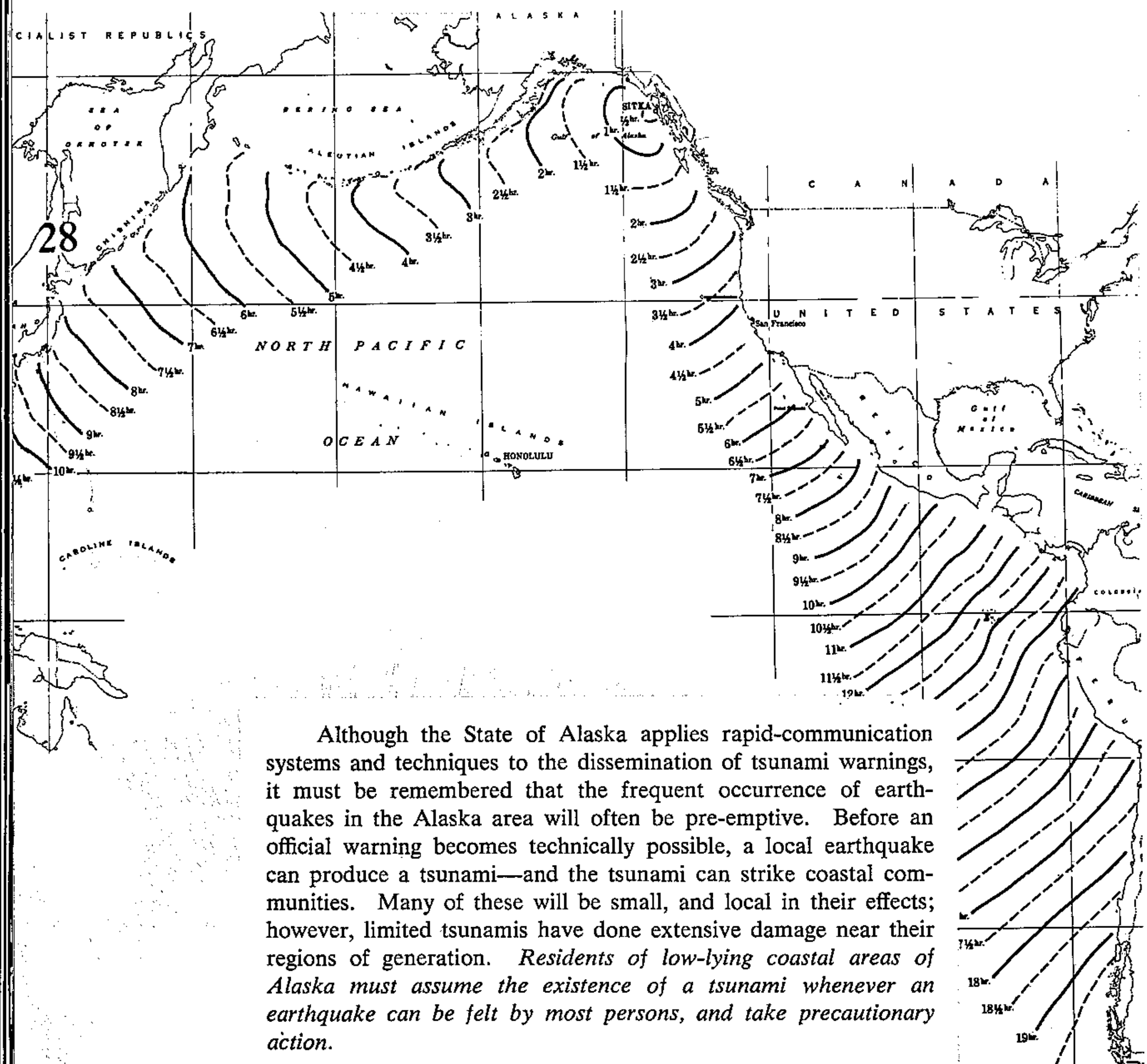
ALASKA

Tsunami bulletins and warnings for Alaska are sent via the FAA communications network to the FAA station, Anchorage; or via the Defense Communications System to the U. S. Air Force Weather Relay Facility, Elmendorf Air Force Base, Alaska. Tsunami messages proceeding by either circuit are then telephoned to the Director, Alaska Civil Defense, in Anchorage.

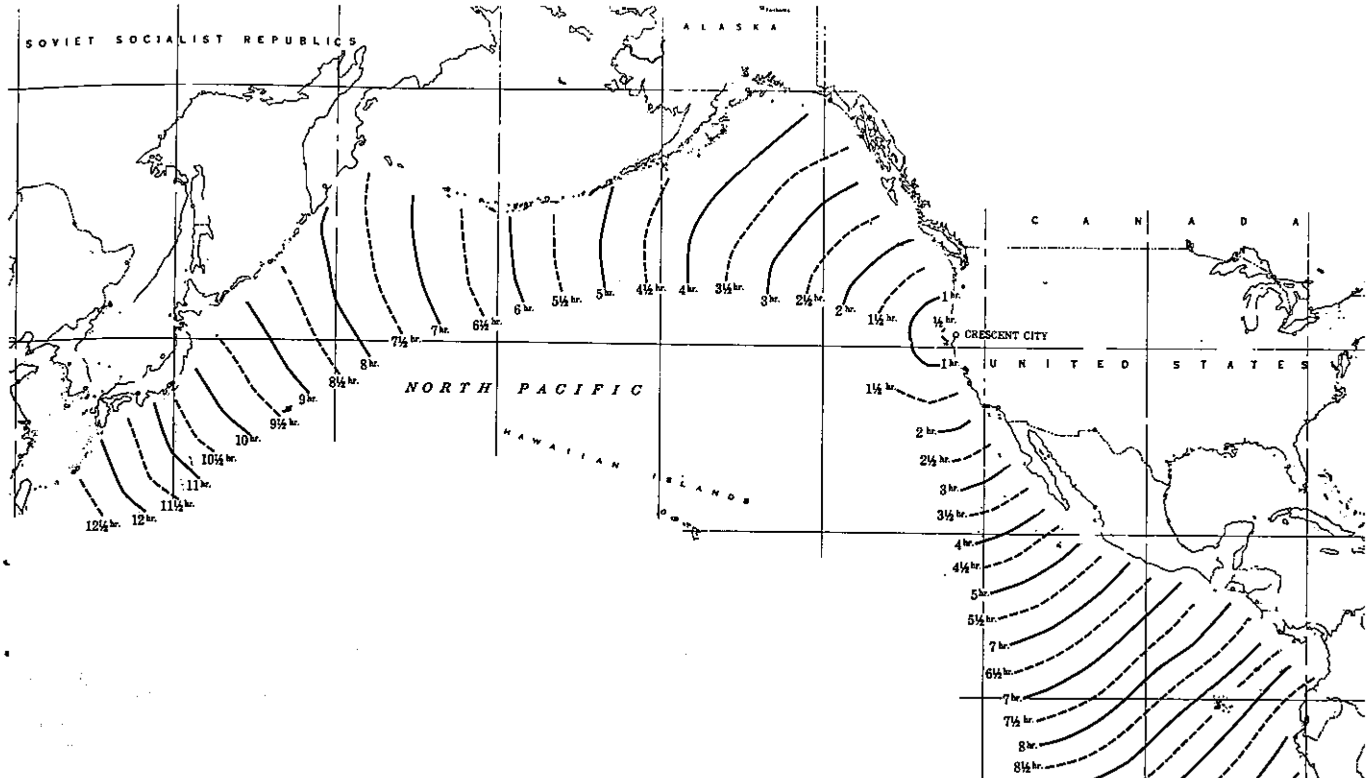


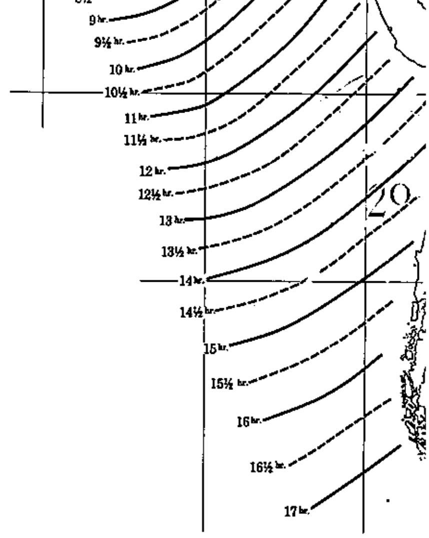
Tsunami traveltime may be calculated from charts shown in this section by locating an earthquake epicenter within the area covered by time curves, and noting its position with respect to the time curves. On this chart, for example, a tsunami generated by an earthquake near Seattle, Washington, would take approximately 4½ hours to reach Kodiak, Alaska.

From Civil Defense headquarters, tsunami messages are relayed first to areas in which the danger appears to be greatest. Where a tsunami endangers a larger area, communication is made with district or area directors of Civil Defense, as well as mayors and municipal police departments. Radio and television stations, newspapers, and wire services are also contacted, and assist in the work of warning the general populace. Major police and fire departments in all areas are alerted, and work in conjunction with district, area, or municipal Civil Defense personnel. The facilities of the U. S. Weather Bureau are employed in carrying warnings to all Alaskan weather stations, which assist in alerting the general public to the imminent danger of a tsunami. These stations are located at Barrow, Barter Island, Kotzebue, Nome, Fairbanks, McGrath, Bethel, St. Paul Island, King Salmon, Cold Bay, Shemya, Anchorage, Cordova, Yakutat, Juneau, and Annette.



Although the State of Alaska applies rapid-communication systems and techniques to the dissemination of tsunami warnings, it must be remembered that the frequent occurrence of earthquakes in the Alaska area will often be pre-emptive. Before an official warning becomes technically possible, a local earthquake can produce a tsunami—and the tsunami can strike coastal communities. Many of these will be small, and local in their effects; however, limited tsunamis have done extensive damage near their regions of generation. *Residents of low-lying coastal areas of Alaska must assume the existence of a tsunami whenever an earthquake can be felt by most persons, and take precautionary action.*

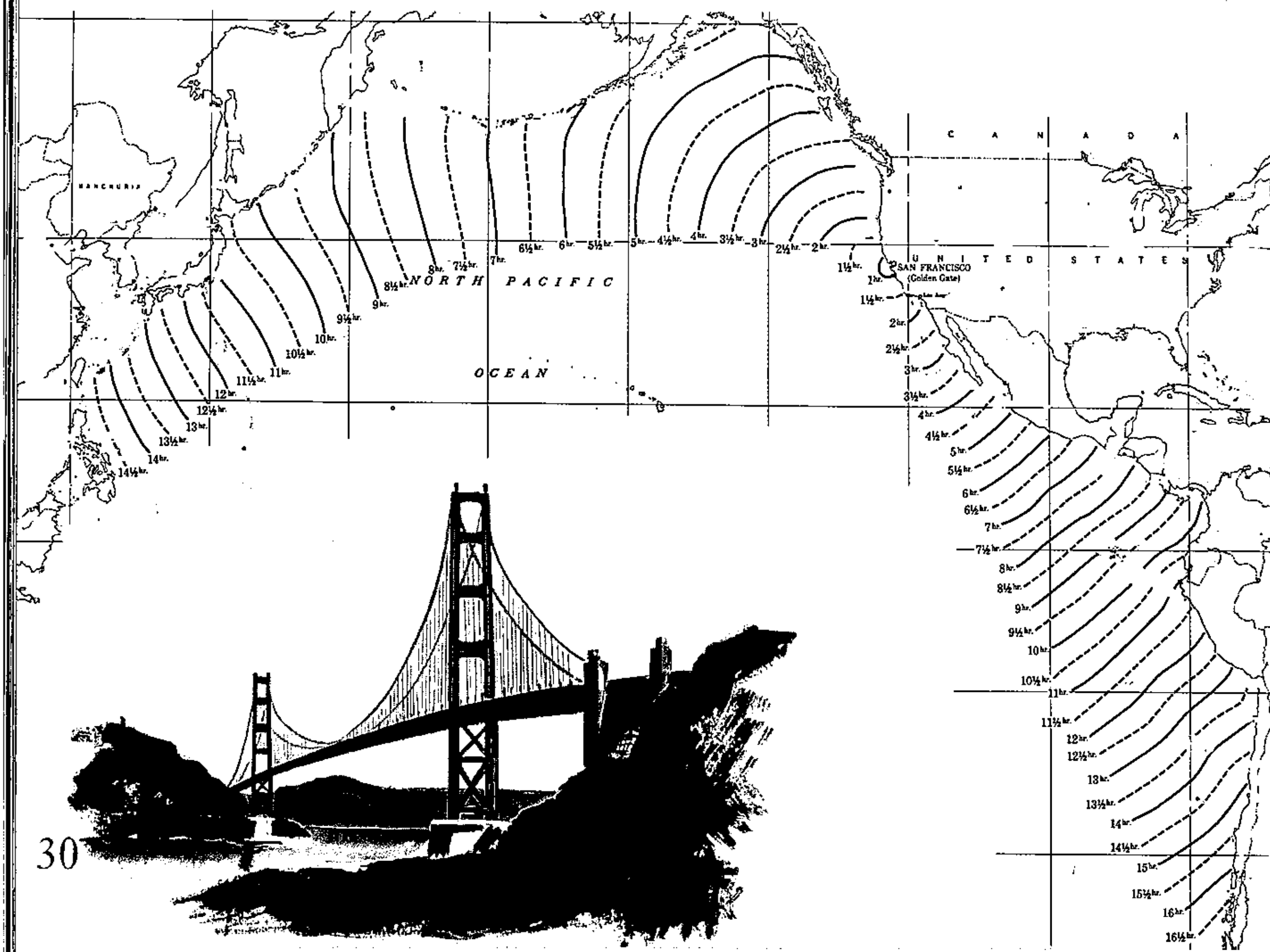




CALIFORNIA
OREGON
WASHINGTON

Tsunami bulletins and warnings for California, Oregon, and Washington are sent via FAA or the Defense Communications System to Department of Army Office of Civil Defense (DOA-OCD), 28th Warning Center, Hamilton Air Force Base, California. From this center, messages are disseminated to established points within each of the three states, via the National Warning System (NAWAS).

In CALIFORNIA, tsunami messages are received by the California Disaster Office (CDO), Sacramento. If this state warning point is inoperative, tsunami messages are routed to the California Highway Patrol, Sacramento. The state Warning Control Officer has the task of evaluating the significance of tsunami messages, and taking necessary *alerting* action in response to them.

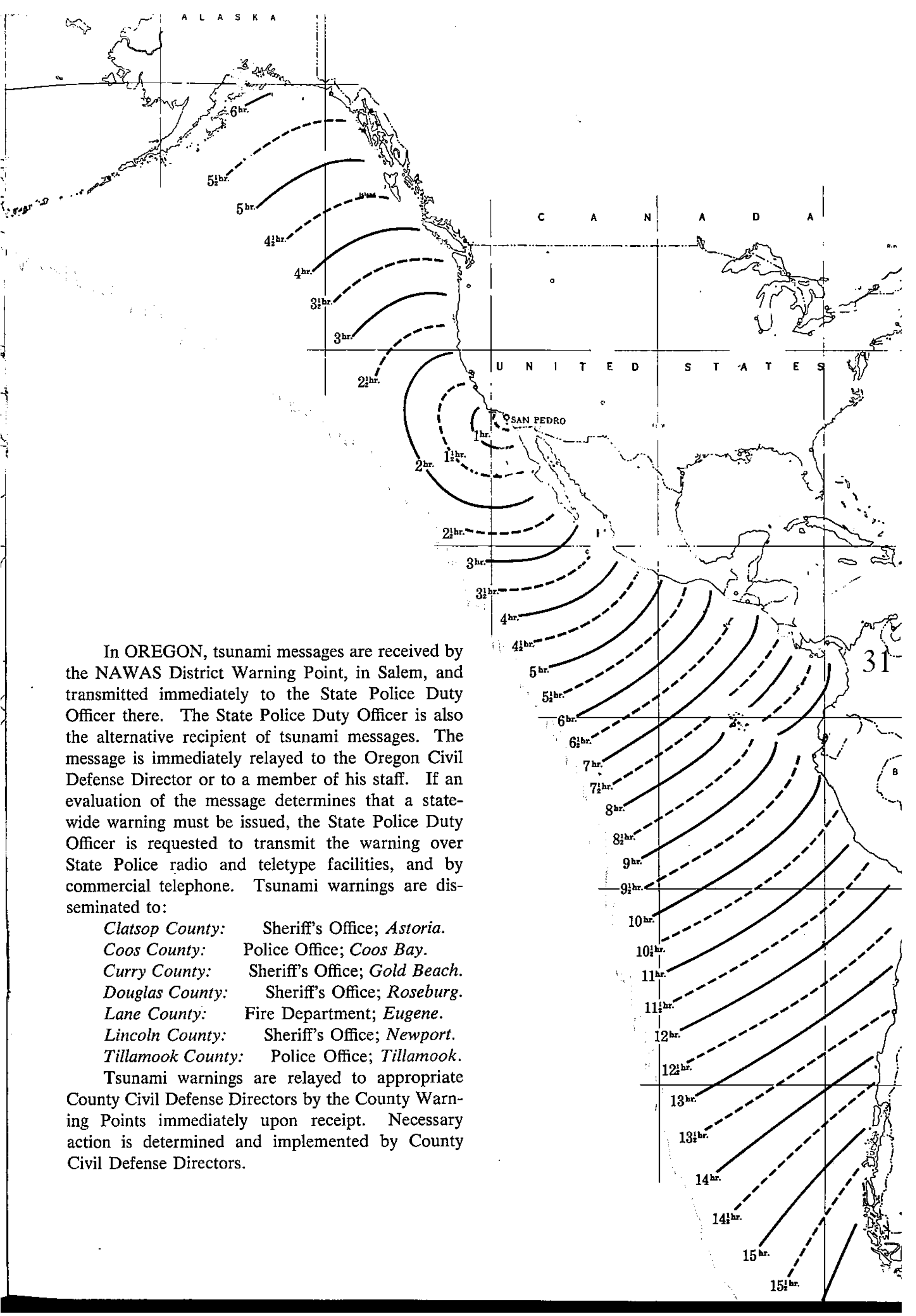


Advisory bulletins are disseminated only when unusual circumstances make such action either necessary or prudent. Warnings are evaluated by the Warning Control Officer and the Director, CDO. Should the Warning Control Officer determine that a state-wide warning must be proclaimed, or should he be directed to do so, he issues an emergency all-points bulletin over the Department of Justice teletype system. This message alerts all Sheriffs, Chiefs of Police, and Civil Defense Directors of coastal counties and cities that a tsunami warning has been received, and provides tsunami ETA's for the California coast; it is issued for the recipients' action or information, as determined by the Warning Control Officer. The same message is broadcast to coastal counties and cities via NAWAS.

The following coastal and bay counties of this state are potentially involved in each tsunami alert:

Alameda	*Marin*	*San Diego*	*Santa Barbara*
Contra Costa	*Mendocino*	*San Luis Obispo*	*Santa Clara*
Del Norte	*Monterey*	*San Mateo*	*Santa Cruz*
Humboldt	*Orange*	*San Francisco*	*Solano*
Los Angeles			*Sonoma*

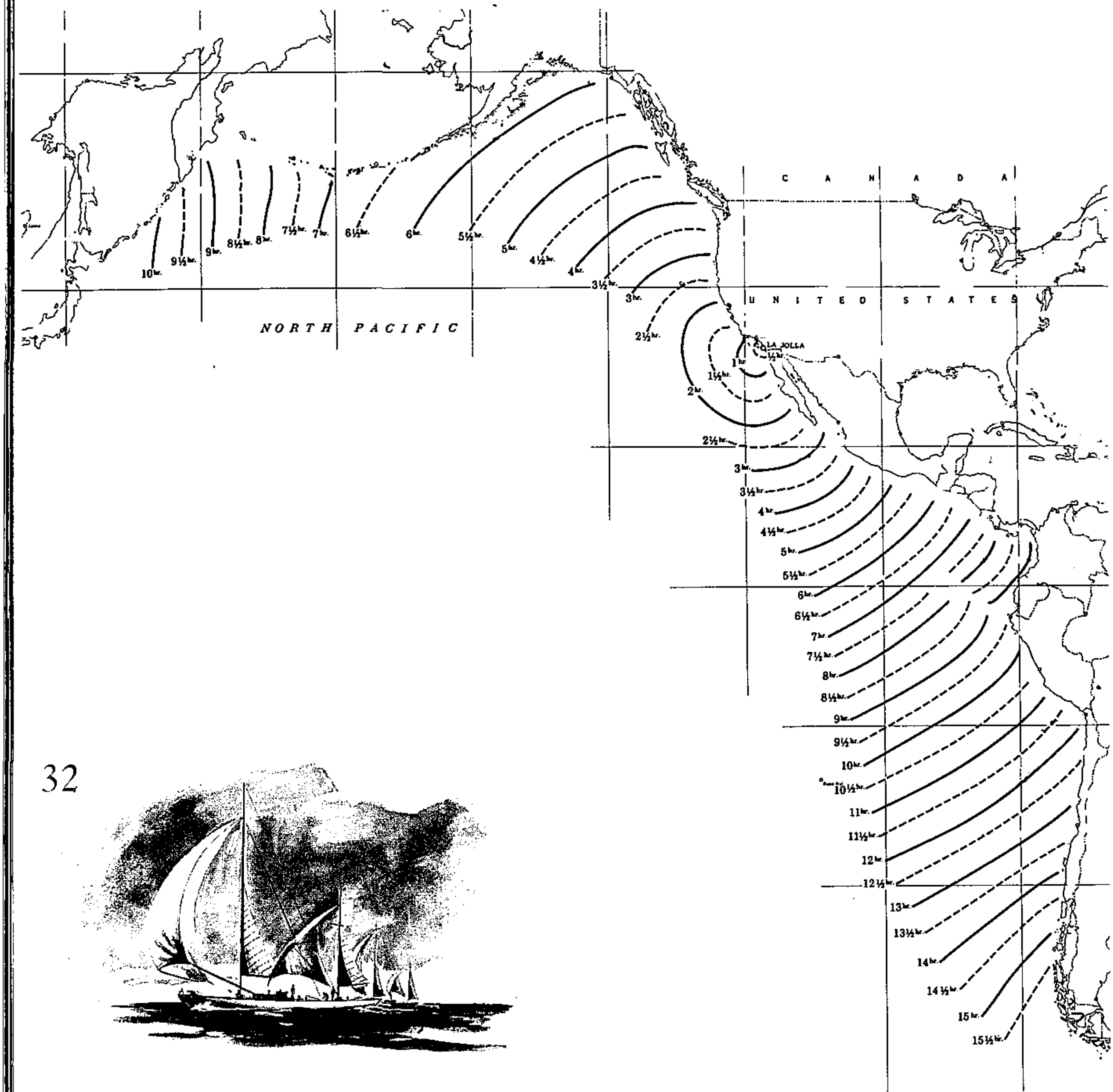
It should be noted that the California Disaster Office does not indicate or direct any action to be taken by local jurisdictions. Determination of such action remains the prerogative and responsibility of local officials.



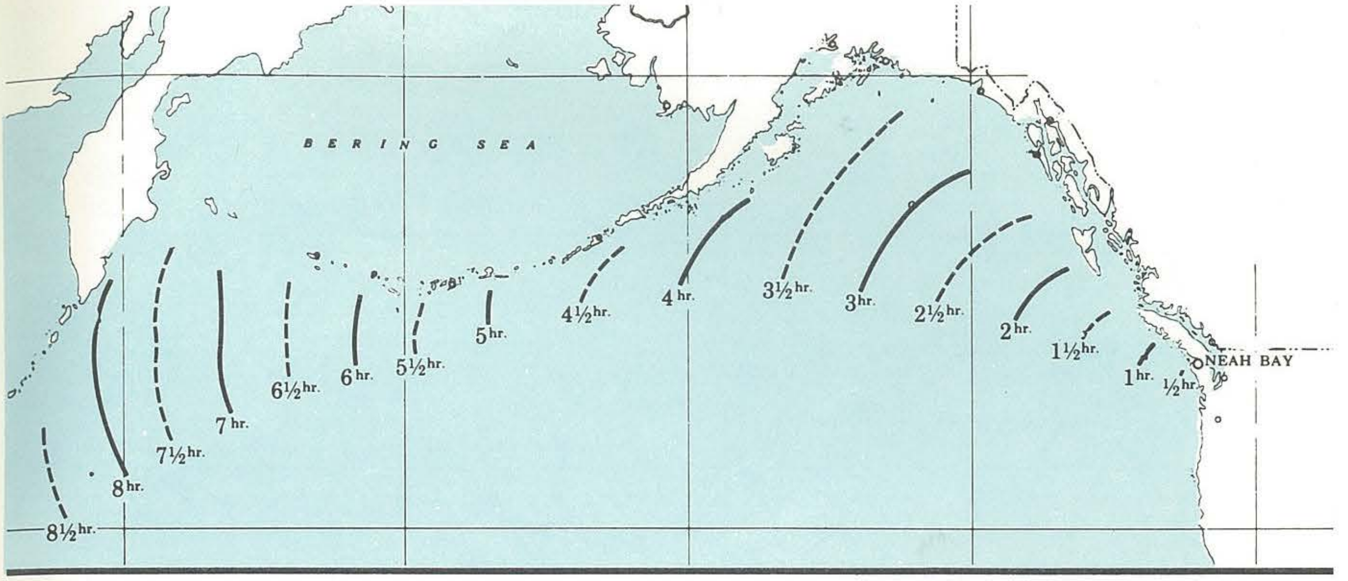
In OREGON, tsunami messages are received by the NAWAS District Warning Point, in Salem, and transmitted immediately to the State Police Duty Officer there. The State Police Duty Officer is also the alternative recipient of tsunami messages. The message is immediately relayed to the Oregon Civil Defense Director or to a member of his staff. If an evaluation of the message determines that a statewide warning must be issued, the State Police Duty Officer is requested to transmit the warning over State Police radio and teletype facilities, and by commercial telephone. Tsunami warnings are disseminated to:

Clatsop County: Sheriff's Office; *Astoria.*
Coos County: Police Office; *Coos Bay.*
Curry County: Sheriff's Office; *Gold Beach.*
Douglas County: Sheriff's Office; *Roseburg.*
Lane County: Fire Department; *Eugene.*
Lincoln County: Sheriff's Office; *Newport.*
Tillamook County: Police Office; *Tillamook.*

Tsunami warnings are relayed to appropriate County Civil Defense Directors by the County Warning Points immediately upon receipt. Necessary action is determined and implemented by County Civil Defense Directors.



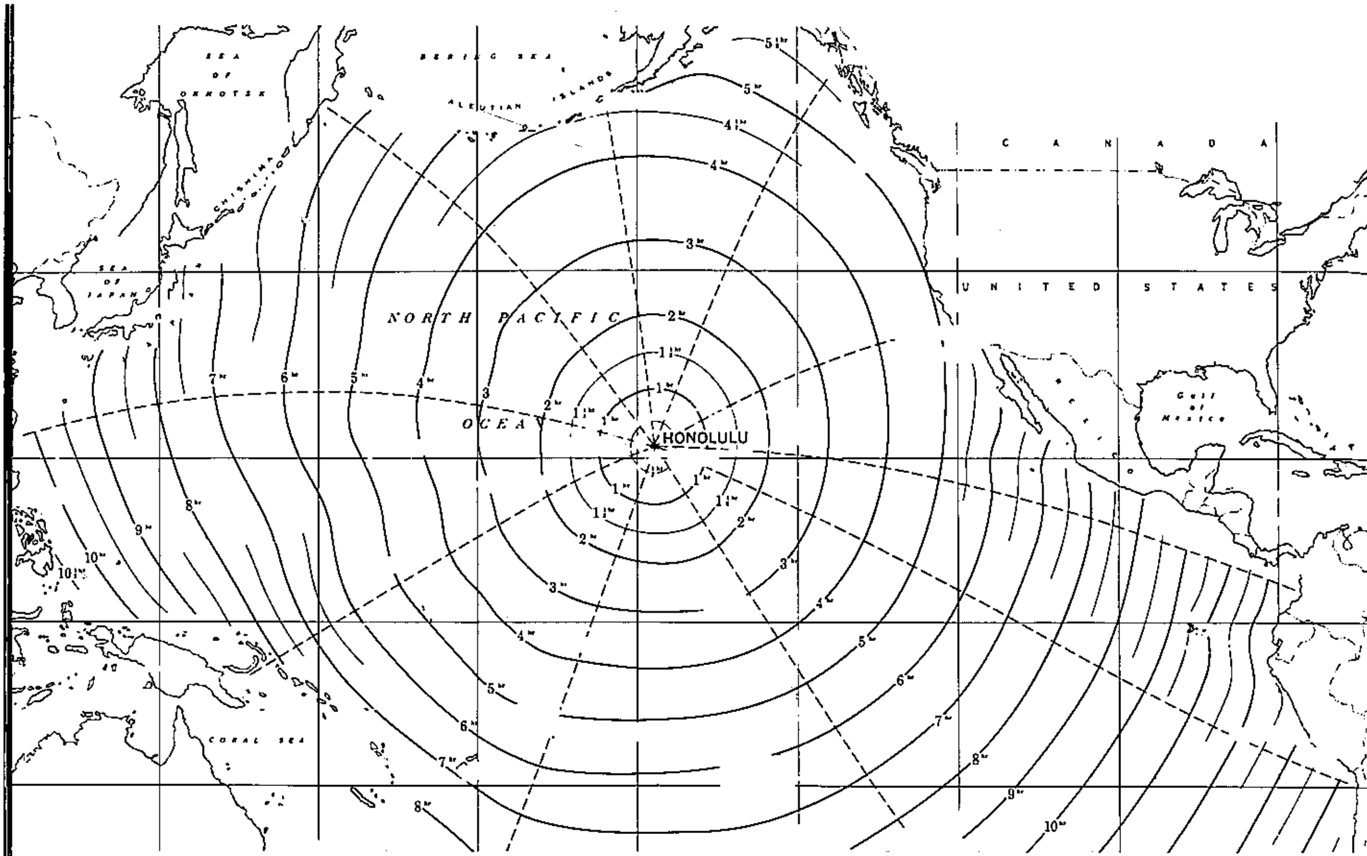
In WASHINGTON, tsunami messages are received by the Washington State Patrol Radio Dispatch Office, Olympia, which acts as the state warning point when the State Civil Defense Control Center is not operated on a 24-hour basis. Either office is equipped to control NAWAS for the state. NAWAS transmissions are also received by 14 additional warning points; of these, seven are used to disseminate tsunami messages along the Washington coast. Upon receipt of a tsunami message, each warning point relays tsunami information to secondary warning points. These, in turn, relay tsunami information to other secondary warning points.



COMMUNICATIONS STRUCTURE
FOR THE STATE OF WASHINGTON

State Warning Point, *Olympia*	State Civil Defense	Sheriff, *Mason County*
	Sheriff, *Thurston County*	Sheriff, *Grays Harbor County* → Sheriff, *Pacific County*
	Police Department, *Olympia* Washington State Patrol, *Chehalis*	Sheriff, *Lewis County*
Washington State Police, *Vancouver*	Sheriff, *Clark County*	
Civil Defense HQ, *Cowlitz County*	Sheriff, *Cowlitz County*	Sheriff, *Wahkiakum County*
Fire Alarm HQ, *Tacoma*	Sheriff, *Pierce County*	
Police, *Renton*	Sheriff, *King County* Police, *Seattle* Pacific Telephone & Telegraph	
Sheriff, *Port Orchard, Kitsap County*	Sheriff, *Jefferson County*	Police, *Port Townsend* Sheriff, *Clallam County* → Police, *Port Angeles*
Police, *Everett*	Sheriff, *Snohomish County*	Sheriff, *Skagit County* → Sheriff, *Island County*
Fire Department, *Bellingham*	Sheriff, *San Juan County* Sheriff, *Whitcom County*	

Messages are transmitted via telephone, Washington State Police radio, and other radio and teletype systems. Recipients of tsunami messages are instructed to "immediately notify by every possible means including personal contact, all persons living in shoreline danger areas."



HAWAII

Tsunami messages for Hawaii are telephoned to the Honolulu Police Department Dispatch Bureau, which in turn transmits messages to the State Civil Defense Agency, and to the civil defense agencies of Oahu, Kauai, Maui, and Hawaii. Upon receipt of tsunami advisory bulletins, police and civil defense officials mobilize personnel as required, and activate the Civil Defense Control Center. The director of the local chapter of the American Red Cross and the general public are notified of present and expected conditions.

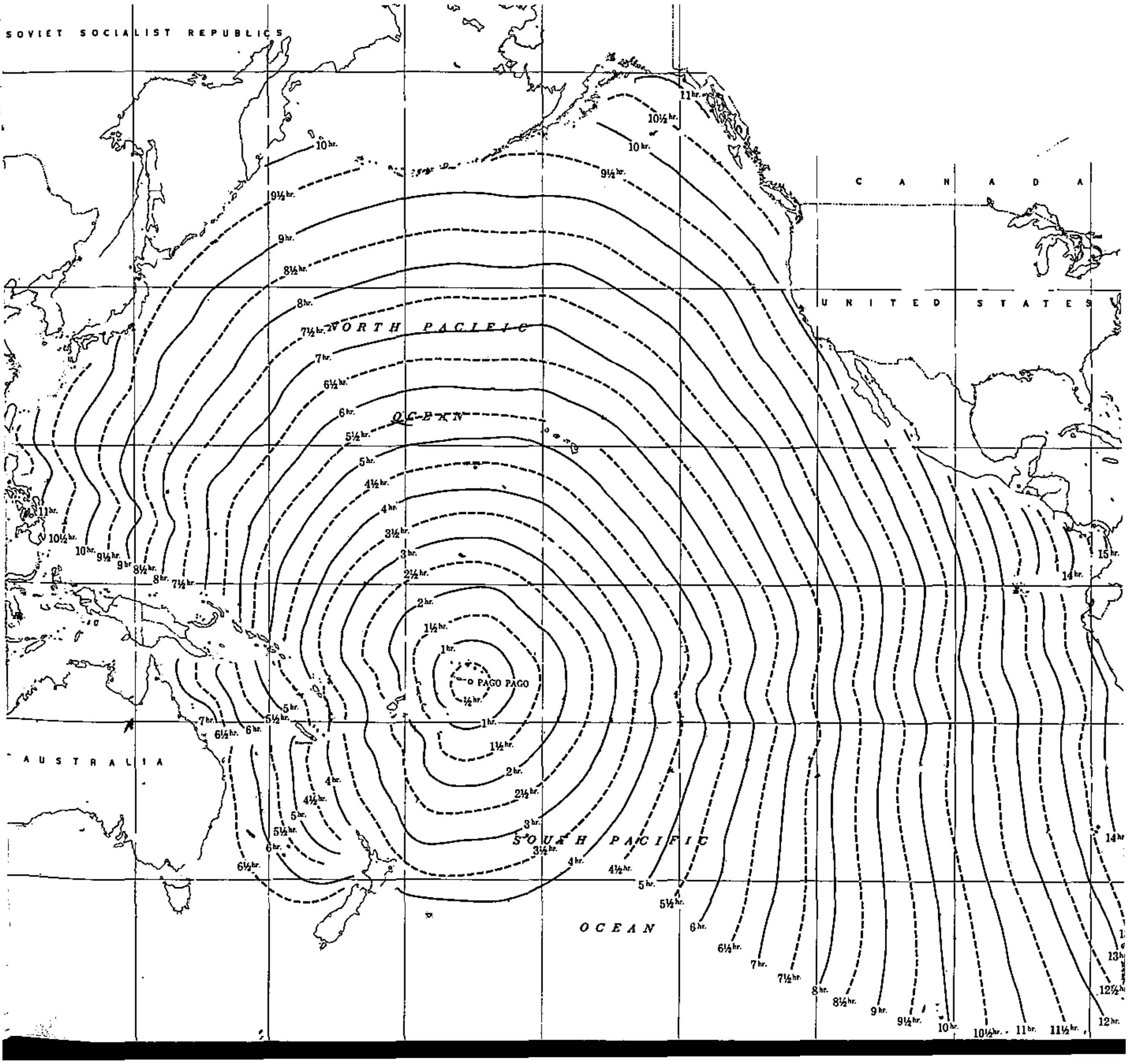
Dissemination to the public uses all communications facilities available to inform residents of coastal areas. When a tsunami warning is received, a series of warning signals are sounded; these are one-minute siren blasts at three-minute intervals, repeated at least five times. Assistance and advice is given in connection with evacuation of all residents of low-lying coastal areas.

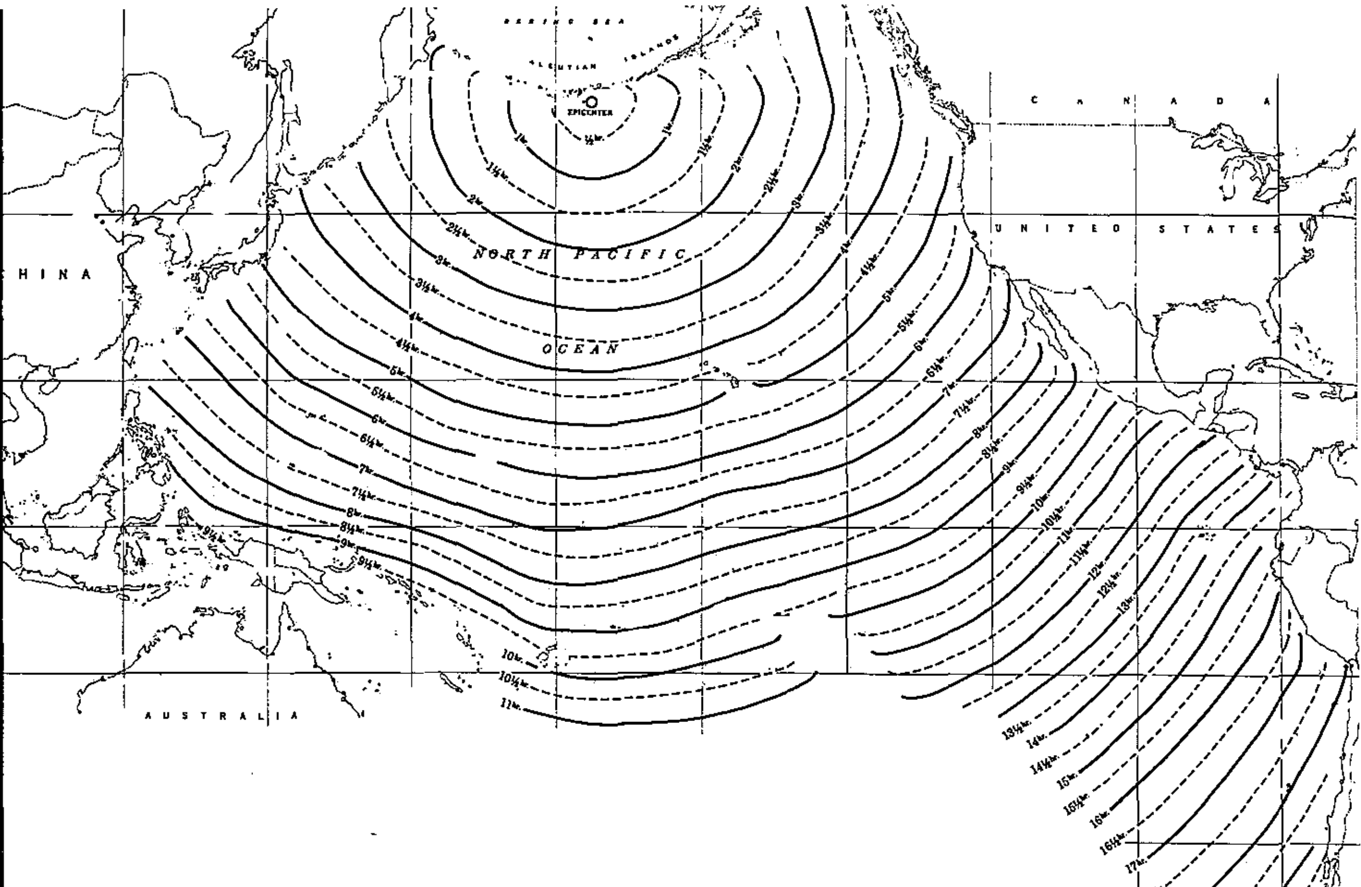
Evacuation from danger areas is advisable but voluntary until a state of emergency has been declared; however, upon this declaration, such evacuation is mandatory when directed and enforced by Civil Defense personnel and police. County police departments are authorized to take necessary steps to prevent sightseers from moving into low coastal areas after a tsunami warning has been issued.

Concurrently, the State Civil Defense activates its Control Center at Fort Ruger, and issues official statements concerning present or expected conditions to radio station KGMB for broadcasting by all stations on their normal frequencies. Such statements are broadcast in the form of numbered Civil Defense Disaster Bulletins. When information is received by the Director, Civil Defense Agency, that all danger has passed, this information is transmitted to the Deputy Director, and to station KGMB and other broadcasting stations for dissemination to the public. In the event of a tsunami disaster, station KGMB and other broadcasting stations inform the public of all wave conditions and damage.

AMERICAN SAMOA

Tsunami bulletins and warnings for American Samoa are sent via the Defense Communications System to the Governor, Pago Pago, and received in the Government Communications Office. The Director of the Port Administration, acting on instructions from the Governor, initiates all necessary warnings to the public. Tsunami warnings are broadcast by radio station WVUV, and a warning siren is used. In addition, a program of public education is planned.





This chart shows tsunami traveltime to all points from a single epicenter in the Aleutian Trench. A tsunami generated here would take approximately 4½ hours to reach Tokyo, Japan, Honolulu, Hawaii, and Vancouver Island; and approximately 18½ hours to reach Valparaiso, Chile.

OTHER U.S. RECIPIENTS OF SSWWS WARNINGS

In addition, the following United States Government offices and installations are notified:

Commander in Chief Pacific; *Honolulu, Hawaii.*
Director, U. S. Coast and Geodetic Survey; *Washington, D. C.*
FAA Flight Service Station; *Honolulu, Hawaii.*
Field Office, U. S. Coast and Geodetic Survey; *Honolulu, Hawaii.*
Office of Civil Defense, Regions 7 and 8.*
Office of Emergency Planning, Regions 7 and 8.*
Regional Office, U. S. Coast and Geodetic Survey; *San Francisco, California.*
U. S. Coast Guard Station; *Attu, Alaska.*
U. S. Naval Base; *Adak, Alaska.*
U. S. Naval Station; *Guam, Mariana Islands.*
U. S. Fleet Weather Central; *Kodiak, Alaska.*
U. S. Naval Station; *Midway Island.*
U. S. Weather Bureau; *Johnston Island.*
U. S. Weather Bureau; *Kwajalein, Marshall Islands.*

Tsunami messages are relayed to other United States Government offices and installations in the Pacific Ocean area via U. S. Pacific Fleet Headquarters; ships and units copying Pacific Fleet broadcasts or mercasts also receive tsunami messages by this channel.

* Region 7, *Santa Rosa, California;* Region 8, *Everett, Washington.*

CANADA

Tsunami bulletins and warnings for Canada are sent via the Defense Communications System to U. S. Navy communications in Seattle, Washington, and from there to the Royal Canadian Navy, Victoria, British Columbia. This agency relays tsunami messages to the Provincial Civil Defense Co-ordinator, in Victoria. The Civil Defense Co-ordinator and his staff, working with representatives of the Royal Canadian Mounted Police, determine the necessity for further dissemination of tsunami messages.

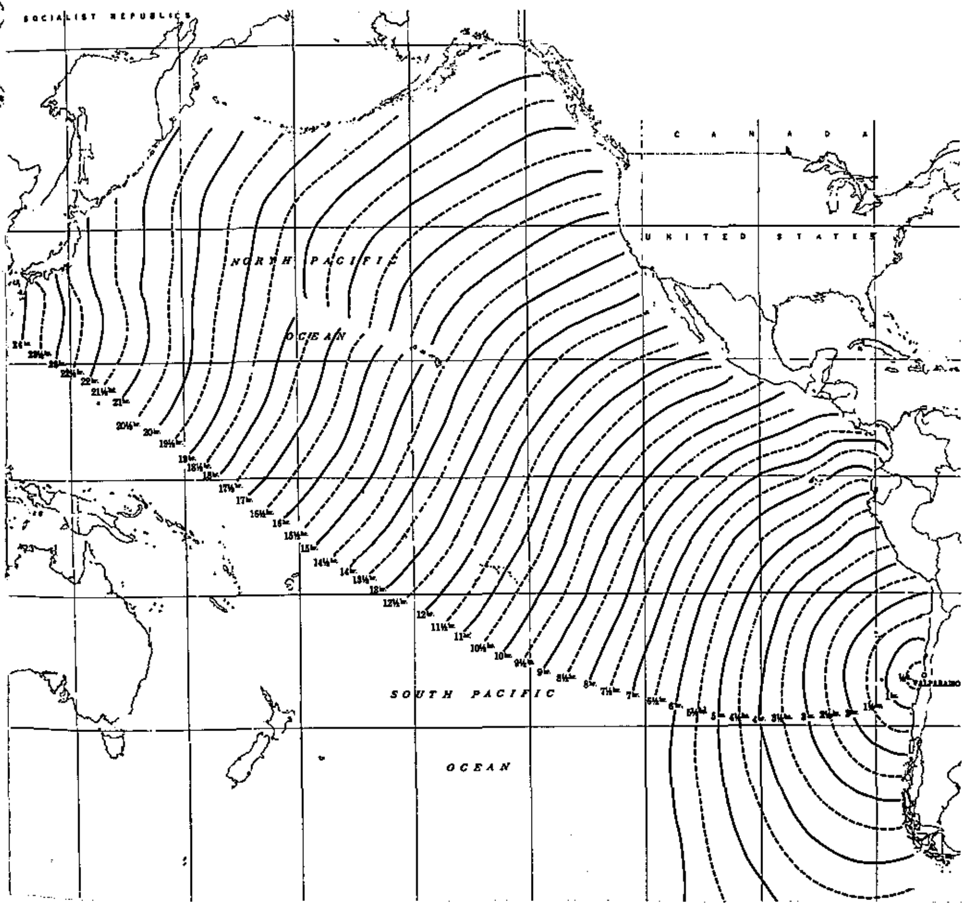
If it is determined that a tsunami message should be disseminated at the local level, R.C.M. Police warn detachment commanders via R.C.M. Police wireless; detachments so notified alert local Civil Defense coordinators, and the mayor or reeve in threatened areas.

As the destructive potential of the tsunami becomes more clear, a general alarm is issued to threatened areas by public broadcast over local radio stations, and municipal officials warn the general populace by all possible means.

CHILE

Tsunami bulletins and warnings for Chile are sent via the Defense Communications System to SPACECONN NASA, Greenbelt, Maryland, and from there via the NASA communication network to the NASA Minitrack Station, Santiago, Chile. This station relays tsunami messages to the *Departamento de Navegacion e Hidrografia,* Valparaiso. An alternate communications plan routes tsunami messages by the Defense Communications System to the U. S. Navy Communications Station, Balboa, Canal Zone; tsunami messages are sent from Balboa to Valparaiso via All America Cables.

Tsunami alerts and warnings are disseminated by the Naval Telecommunications Service, the Coastal Radiotelephone Service, and the Lighthouse Radiotelephone Service. In addition, warnings are disseminated by the Ministry of the Interior, which controls the State Telegraph and the Telephone Company of Chile. From north to south, these Chilean ports are alerted:



Arica
Iquique
Tocopilla
Antofagasta
Taltal
Chañaral
Caldera
Easter Island
Coquimbo
Quintero
Valparaiso
Juan Fernández Islands
San Antonio
Tomé
Lirquén
Talcahuano
Coronel
Lota
Lebu
Corral
Ancud
Puerto Montt
Achao
Quemchi
Castro
Yelcho
Quellón
Melinka
Aysén
San Pedro
Guarello
Muñoz Gamero
Evangelistas
Punta Arenas
Williams
Navarino
Bahía Orange
Diego Ramírez
Base Prat (Antarctica)

Each of these ports has at its disposal easy communications with other, smaller ports or harbors. The Maritime Authority has the responsibility of transmitting secondary alerts. It is also possible to disseminate tsunami messages to the Chilean lighthouses shown below:

Punta Angeles	*Tumbes*	*Raper*
Curaumilla	*Hualpen*	*Fairway*
Panulcilla	*Santa María Island*	*Felix*
Carranza	*Mocha Island*	*Magallanes*
Quiriquina	*Galera*	*Delgada*
Talcahuano	*Corona*	*Dungeness*

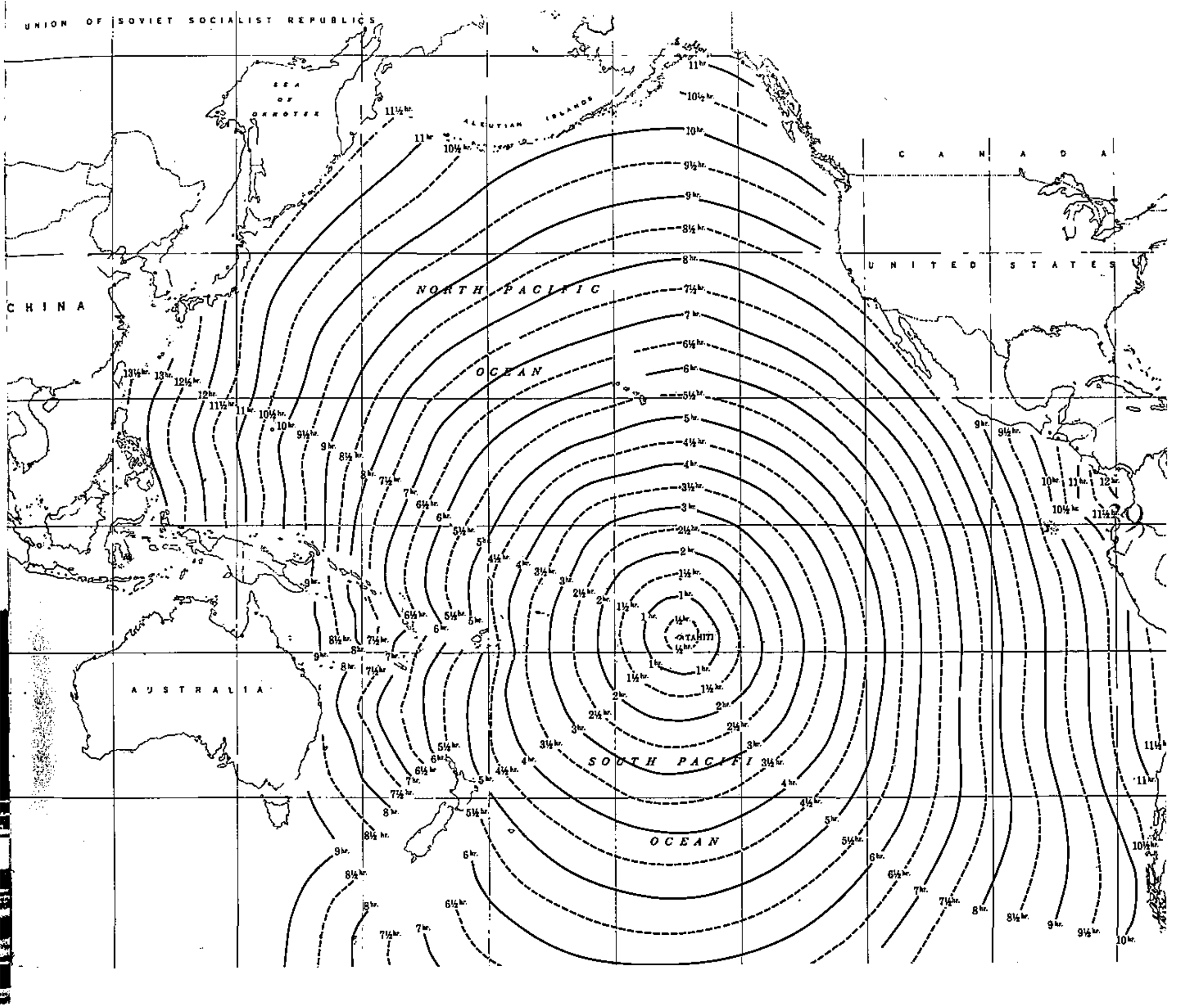
The coast of Chile, like those of Alaska and Japan, lies in the circum-Pacific seismic belt: earthquakes along this coast have generated scores of large, destructive tsunamis, and a legion of smaller, local ones. The great waves are called *maremotos* by the people of Chile, whose experience with the waves' destructive potential corresponds to that of the Japanese. At present, no seismic sea-wave warning network is in operation at the local level in Chile.

FIJI ISLANDS

Tsunami bulletins and w[illegible] Islands are sent via FAA comm[illegible] to the Aeronautical Communications Station, Nandi, Fiji, and [illegible] Royal [illegible] Force Station, Lauthala Bay. This activity telephones tsunami messages to the Harbour Master in Suva; the Harbour Master is responsible for disseminating tsunami warnings to the general public on the inhabited islands of this group.

FRENCH POLYNESIA

Tsunami messages for French Polynesia are sent via FAA communications to the Aeronautical Communications Station, Nandi, Fiji, and from there via radio telegraph to the Aeronautical Communications Station, Papeete, Tahiti, for notification of the Chief of the *Mission Hydrographique,* in Papeete. This office is responsible for dissemination of tsunami warnings to the people inhabiting the islands of French Polynesia.



HONG KONG

Tsunami bulletins and warnings for Hong Kong are sent via FAA communications to the Philippine CAA communications station, Manila, and relayed to the Royal Air Force Communications Center, Hong Kong. This activity notifies the Director, Royal Observatory. Warnings are disseminated over the Hong Kong Government Information Services Department teleprinter line to all local radio stations and newspapers, in the form of official announcements. In 1964, these techniques were augmented by the display of visual warning signals at selected stations in the Hong Kong area.

JAPAN

Tsunami bulletins and warnings for Japan are sent via the Defense Communications System to the Air Force Communications Service Weather Relay and Broadcast Center, and relayed to the Japan Meteorological Agency (JMA) and its Seismological Section.

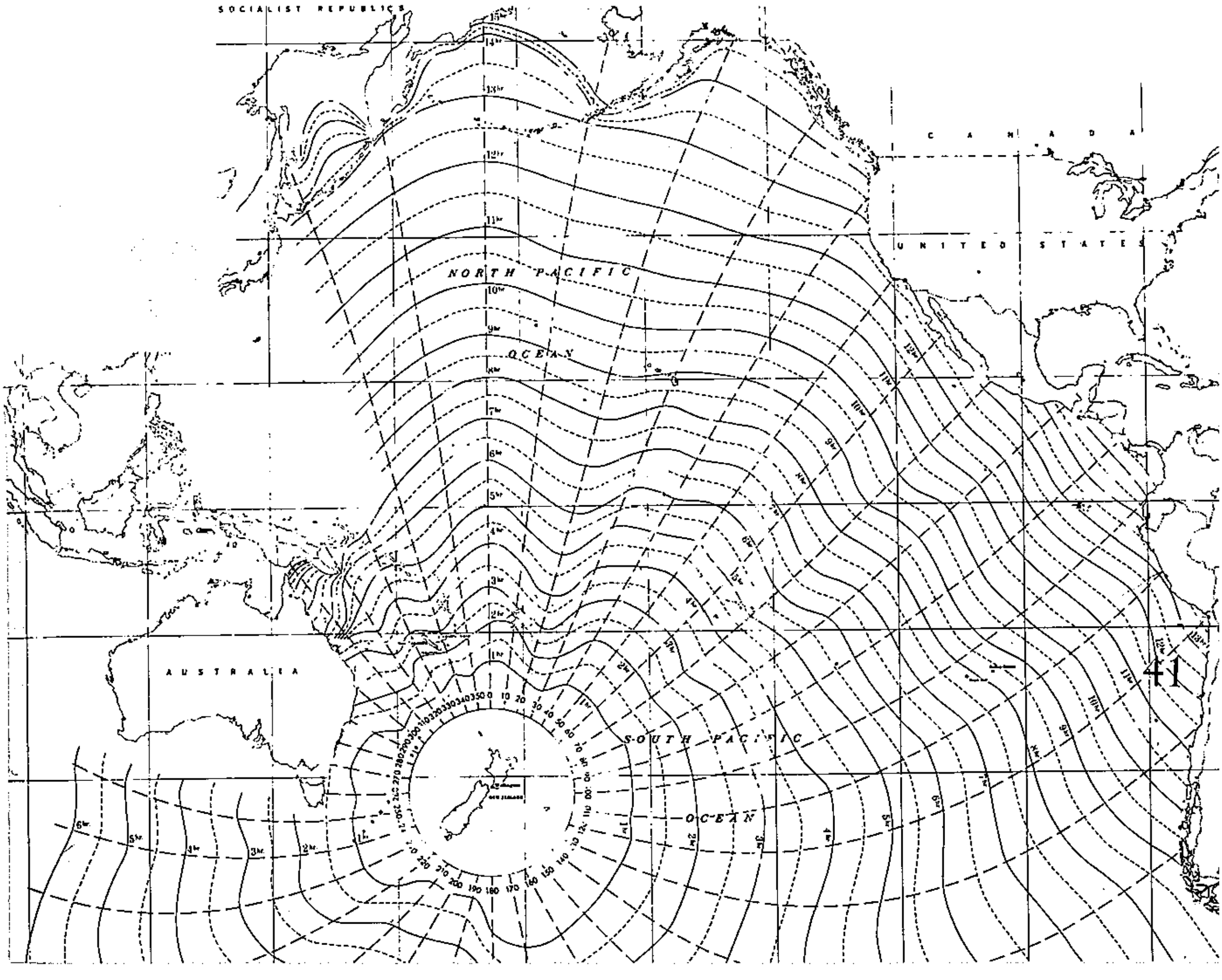
Japan's long and painful association with tsunamis has given that nation the necessary impetus to formulate a model tsunami warning system at the local level. This system was initiated in 1957, operating through JMA facilities. It should be noted that the JMA system is the independent warning apparatus of the Government of Japan, and not an administrative or functional extension of the SSWWS; however, the two systems work in close cooperation, which includes the exchange of seismic and tidal data. One JMA seismological station, and two tide gages, cooperate as part of the Pacific SSWWS.

The JMA tsunami warning system is concerned with tsunamis of both local and distant origin. In either instance, the JMA system operates in much the same way; the difference lies in the dependence of Japan upon the SSWWS, and allowable response-time. Five of JMA's seismological stations are designated as tsunami centers; 26 others act as tsunami warning system components. System operations are applied to 14 divisions of the Japanese coast, each under the cognizance of tsunami centers in Sapporo, Sendai, Tokyo (JMA), Osaka, and Fukuoka. The 26 associated tsunami warning system stations report seismological data to appropriate tsunami center within 10 minutes of the occurrence of an earthquake, provided the shock has certain minimum characteristics of intensity or magnitude previously established by JMA. Tsunami centers determine the earthquake's epicenter, estimate magnitude, and issue a tsunami forecast stating whether or not a tsunami is probable, and whether the tsunami is likely to be minor (little damage) or major (destructive). Where circumstances warrant, tsunami centers are authorized to issue information to the general public on the basis of their seismological data. These procedures work very well with tsunamis of local origin. Tsunamis of distant origin (*e.g.*, Alaskan and Chilean tsunamis) require closer coordination between the JMA system and the SSWWS.

Tsunami warnings to the general public are disseminated to municipalities and to the general public by NHK radio, and the facilities of the Nippon Telegraph and Telephone Public Corporation, National Police Agency, the Maritime Safety Agency, and Japan National Railways. In some coastal districts, roadsigns advise the public of the symptoms preliminary to tsunamis, and most villages have warning bells. But there is no substitute for experience, as shown by the following anecdote:

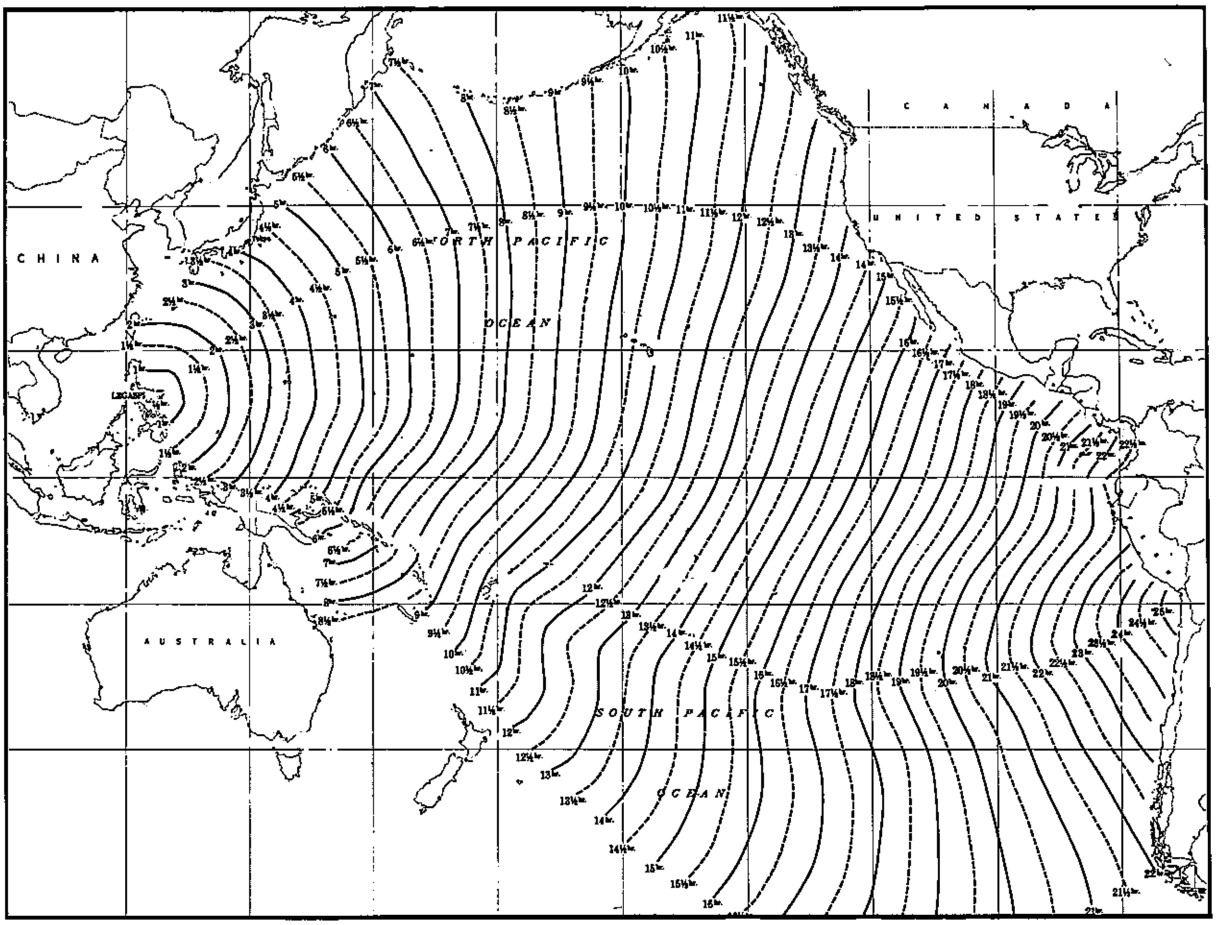
> *At the time of the Chile tsunami of May 1960 . . . no general advance warning was issued* [in Japan] *. . . and hundreds of people were killed or injured by the battering waves. In Miyako, however, the aged mother of the mayor was awakened by the rattling of boulders in a nearby estuary, the sound being transmitted from the floor to her ear through the traditional Japanese wooden pillow. She roused her son, who confirmed her fears that the sound resulted from the retreat of water signalling the approach of a tsunami, and he sounded the alarm by ringing the warning bells. Although the waterfront of Miyako was shattered, none of its citizens were caught by the waves. It seems unlikely that advances in theoretical understanding can ever replace the kind of common sense . . . that saved Miyako.**

* D. C. Cox, *Status of Tsunami Knowledge,* an introduction to the tsunami meetings of the Tenth Pacific Science Congress at the University of Hawaii, Honolulu, August-September 1961. Until the Chile tsunami of May 1960, it was not known that a tsunami of such distant origin could produce such devastating effects in Japan; the consequent underestimation of tsunami risk led to there being no general warning issued by the JMA system prior to the wave's arrival. The SSWWS warning was issued to all participants some 12 hours before the first wave's arrival in Japan.



NEW ZEALAND

Tsunami bulletins and warnings for New Zealand proceed via the FAA network to the Aeronautical Communications Station, Nandi, Fiji Islands; or via U. S. Navy communications to Christchurch, New Zealand. Messages from Fiji or Christchurch are transmitted via New Zealand's CAA communications network to Wellington, and relayed to the Civil Defence Officer. Upon receipt, the message is coordinated between the Ministry of Civil Defence and, Department of Scientific and Industrial Research, and evaluated in terms of wave arrival time at various points along the coasts and potential danger. If it is decided that a general alert is necessary, and if such alert is authorized, a coded message is transmitted by the Post Office to local or group Civil Defence Controllers. At the same time, arrangements are made with the Broadcasting Service to transmit appropriate warning messages. Sound devices, activated by Civil Defence Controllers, alert the general populace to listen for wireless broadcasts of the emergency warning.



REPUBLIC OF THE PHILIPPINES

Tsunami messages for the Republic of the Philippines are sent via FAA communications to the Philippine CAA communications station, MANILA, and delivered to the Duty Forecaster of the Weather Bureau's Forecasting Center. Distribution of tsunami messages includes the Director of the Weather Bureau, and that organization's Central Office and Geophysical Observatory. The Philippine Bureau of the Coast and Geodetic Survey also receives tsunami messages via the Weather Bureau's Central Office. Responsibility for dissemination of tsunami warnings in the Philippines rests solely with the Weather Bureau. The Geophysical Observatory evaluates the tsunami messages, and, in conjunction with the Central Office, sees to the dissemination of warnings to:

National Civil Defense Administration
Malacanang (Presidential Committee on Relief and Rehabilitation)
Weather Bureau Forecasting Center
Weather Bureau Field Stations
Press Offices and Radio Stations
Provincial Governors

Telephone, radio-telephone, and telegraph facilities are used in the dissemination of tsunami warnings. Distribution of warnings is generally restricted to provinces susceptible to damage by tsunamis.

TAIWAN

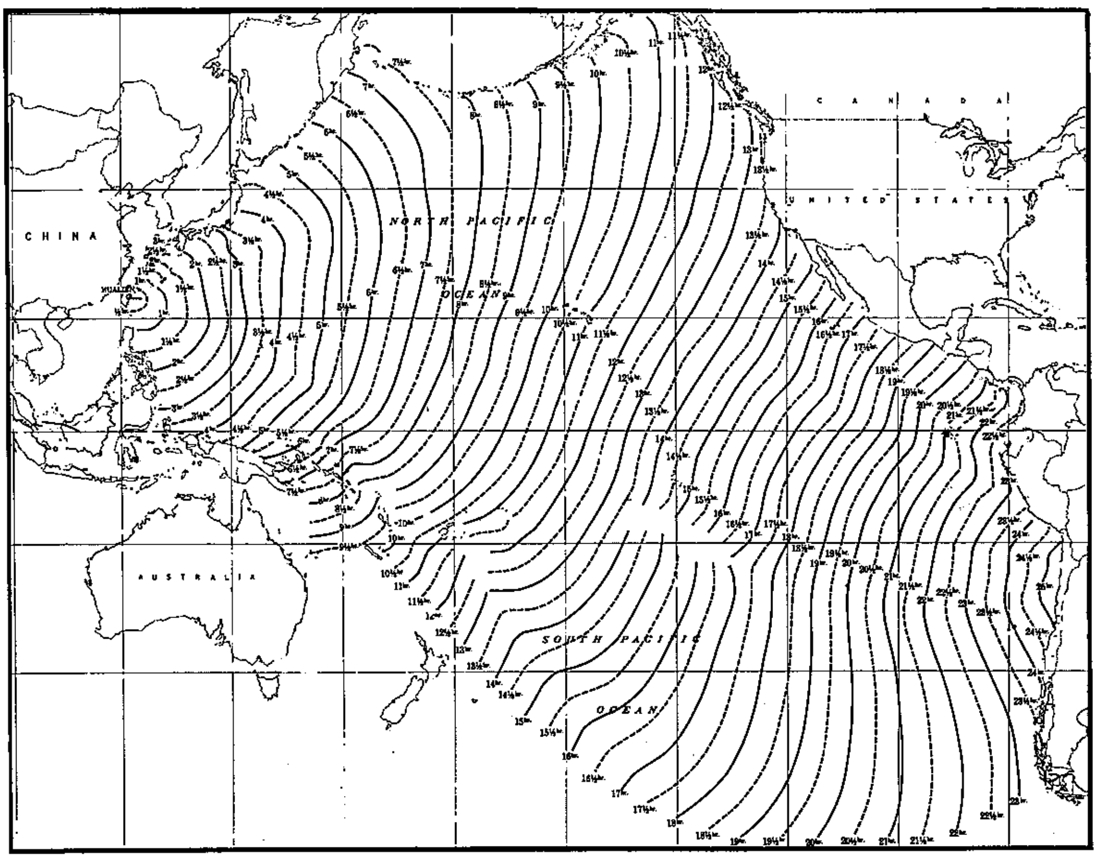
Tsunami bulletins and warnings for Taiwan are sent via the Defense Communications Network to Taiwan Defense Command Communications Center, Taipei, and telephoned to Taiwan Weather Bureau. The Director, Taiwan Weather Bureau, is the official responsible for dissemination of tsunami warnings to these Weather Bureau sub-stations:

Penchiayu	*Keelung*
Shinchu	*Tansui*
Penghu	*Iran*
Taichung	*Hualien*
Tainan	*Shingkang*
Kaoshung	*Taitung*
Jiyuehtan (Sun-Moon Lake)	*Tawu*
	Hengchun
Alishan	*Langyu*

Officials at these stations see to the dissemination of tsunami warnings to the general public.

WESTERN SAMOA

Tsunami bulletins and warnings for Western Samoa are sent via FAA communications to the Aeronautical Communication Station, Nandi, Fiji, and relayed by radiotelegraph to Apia Radio or CAA, Faleolo Airport. These recipients pass tsunami messages to the observer-in-charge, APIA Observatory. The observer-in-charge, acting through the Secretary to the Government of Western Samoa, is responsible for dissemination of tsunami warnings. Methods of dissemination include local radio broadcasts and personal contact with people in areas where tsunami danger is greatest.

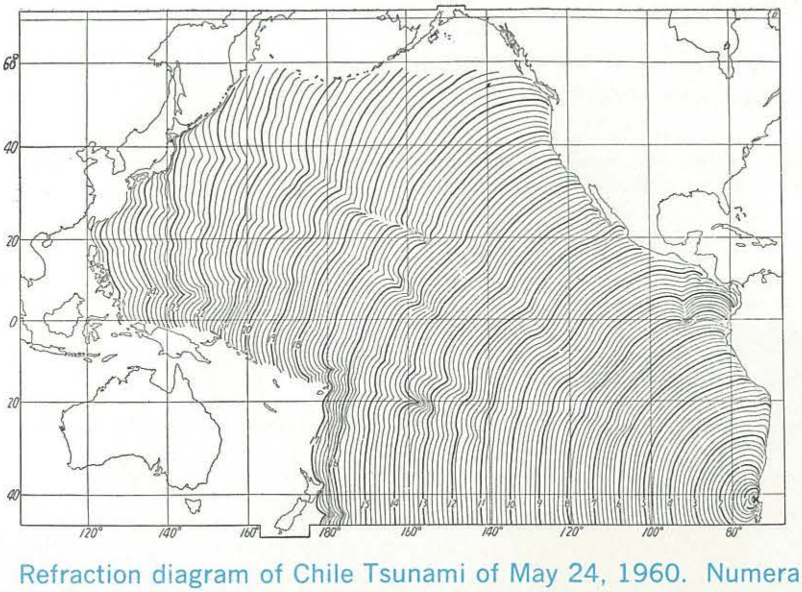


Improvements in the

SSWWS

Over the years, the number of casualties caused by tsunamis has diminished substantially. The day is past when tsunamis of distant origin can come upon Pacific islands and continental coasts unexpectedly, to claim lives by the hundreds or thousands. The Seismic Sea-Wave Warning System has played a central part in the reduction of tsunami casualties.

But its effectiveness is restricted by man's imperfect knowledge of his planet. The U. S. Coast and Geodetic Survey is attempting to improve the amount and quality of that knowledge through programs in advanced seismological theory and techniques, tsunami research, geophysical research and development, and oceanography.

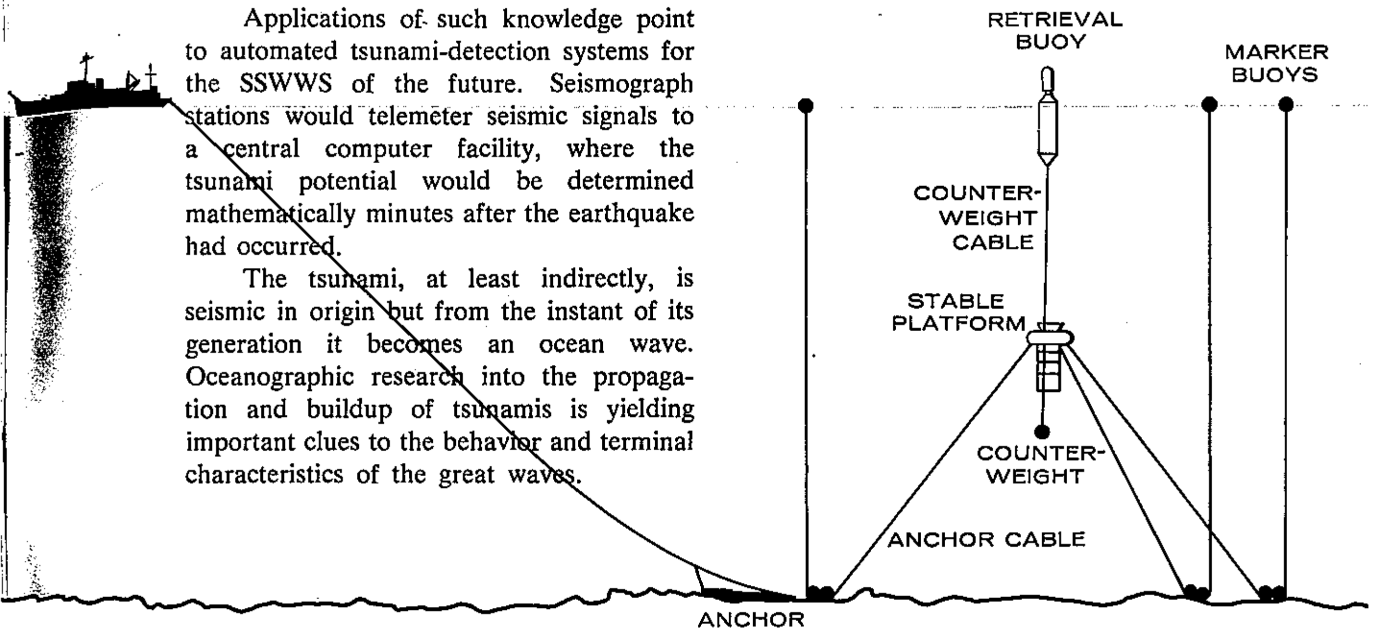


Refraction diagram of Chile Tsunami of May 24, 1960. Numerals indicate hours of traveltime from epicenter. (The Committee for the Field Investigation of the Chilean Tsunami of 1960, **Report on the Chilean Tsunami of May 24, 1960, as Observed Along the Coast of Japan, December 1961.)**

The causes of seismic sea-waves are not positively known, and it remains for science to determine their specific characteristics of generation, propagation, and buildup. Studies are underway to evaluate the types of ground motion associated with tsunami generation, and to correlate earthquake focal mechanisms with tsunami generation, in the hope that those characteristics which cause tsunamis may be differentiated and identified. Development of wave-refraction charts for past tsunamis, showing areas of wave concentration, may be a first step toward prediction of tsunami wave heights. Associated instrumentation now under development includes deep-ocean tide gages and pressure sensors, to detect passing tsunamis in the open ocean; and devices which register the directional component of earth movement around a fault, detecting tsunami-generating crustal displacements in submarine regions.

Applications of such knowledge point to automated tsunami-detection systems for the SSWWS of the future. Seismograph stations would telemeter seismic signals to a central computer facility, where the tsunami potential would be determined mathematically minutes after the earthquake had occurred.

The tsunami, at least indirectly, is seismic in origin but from the instant of its generation it becomes an ocean wave. Oceanographic research into the propagation and buildup of tsunamis is yielding important clues to the behavior and terminal characteristics of the great waves.

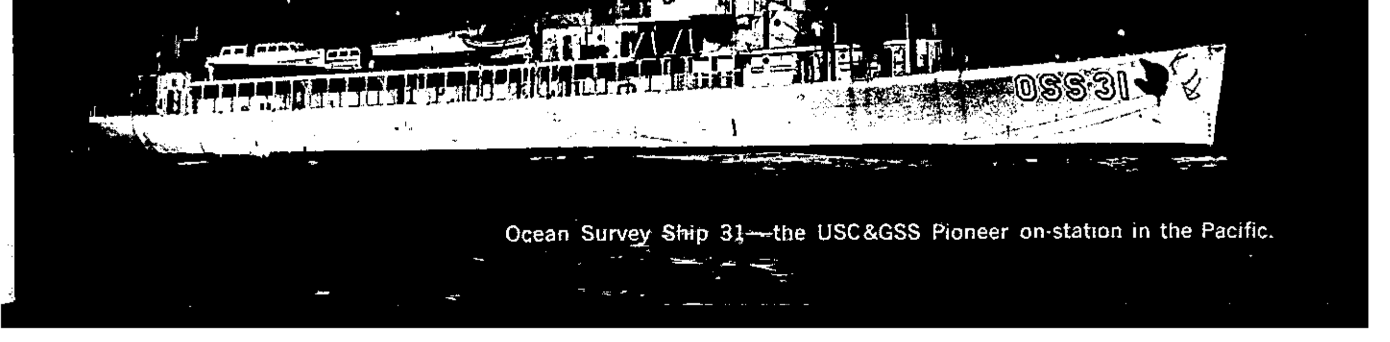


General arrangement, underwater stable platform

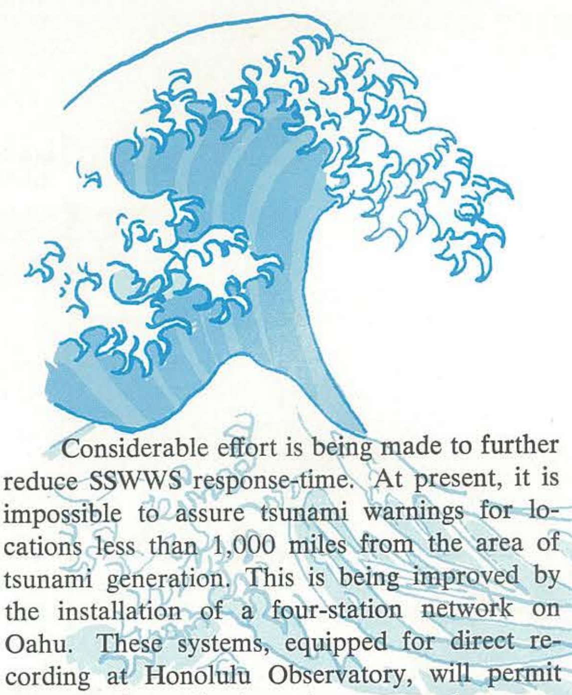
Bathymetric analysis of the island-arc and trench structures of the Pacific provides a basis for seismological and geological interpretations of the configuration of the ocean floor. Bathymetry also reveals the general configuration of the Pacific Basin; because the local shape of the ocean floor is the major determinant of tsunami velocity and buildup, such data are critical to an improved understanding of tsunamis.

Studies of the gravity and magnetic characteristics in the Pacific island arcs and trenches provide indications of the crustal structure beneath the sediment cover of the ocean floor. These sediments are sampled, and the rock structure below is probed to measure heat-transfer between the solid earth and ocean; and powerful echo-profilers have been developed to chart sub-bottom crustal strata.

Bathymetric model, Adak Canyon, Aleutian Island Arc.



Ocean Survey Ship 31—the USC&GSS Pioneer on-station in the Pacific.



Considerable effort is being made to further reduce SSWWS response-time. At present, it is impossible to assure tsunami warnings for locations less than 1,000 miles from the area of tsunami generation. This is being improved by the installation of a four-station network on Oahu. These systems, equipped for direct recording at Honolulu Observatory, will permit epicenter-determination minutes after the occurrence of an earthquake, somewhat reducing SSWWS response-time.

Still, something additional is needed at the local level. The U. S. Coast and Geodetic Survey encourages the development of parallel warning systems that have the capability to locate earthquakes, determine their tsunami-generating potential, and warn affected areas. Local systems provide positive warnings of tsunami generation for the people near the earthquake epicenter, where a tsunami may strike within minutes of the initial shock.

Japan operates a system of this type, which cooperates in the SSWWS. Many of the tsunamis felt by Japan originate a relatively few miles offshore, and there is a consequent reduction in the allowable response-time of the Japanese system; nevertheless, this system operates reliably within its stringent time restrictions, and has saved thousands of lives. The USSR, which does not participate in the SSWWS, also operates a limited system for the Kurile-Kamchatka coast, northwest of Japan. A local tsunami warning network in Alaska and the Aleutian Islands would have reduced casualties during the earthquake of March 28, 1964.

The U. S. Coast and Geodetic Survey has taken the first steps in the development of a local tsunami warning network for the people of Alaska. An extensive network of seismological instruments has been installed in the Prince William Sound area and at selected points in the Aleutians. The primary purpose of this network is to obtain information necessary to effective analysis of Alaskan earthquakes. Ultimately, it will be the instrumentational foundation for a local tsunami warning system, giving Alaska an independent capability for the detection and location of earthquakes and seismic sea-waves—and the means of providing early warning of destructive tsunamis. This system will function as an integral unit of the Pacific SSWWS.

The short time-span and potential seriousness of a tsunami emergency require that the general public be kept constantly informed. In 1964, a cooperative arrangement was made with the U. S. Weather Bureau to ensure the broadest possible dissemination of SSWWS messages. Under this arrangement, tsunami bulletins for the United States can be issued directly to the general public through the Weather Bureau's links with radio and television stations. The effectiveness of this method of public warning has been demonstrated by the Hurricane Warning Service operated by the U. S. Weather Bureau. This addition to the SSWWS makes it possible for persons in endangered areas to take steps preliminary to evacuation, and greatly facilitates the work of the Civil Defense and other responsible emergency organizations.

As SSWWS participation increases, and additional tsunami warning systems are developed at the local or regional level, the Seismic Sea-Wave Warning System must accrue the means of accommodating an expanding mission. Its effectiveness has improved in recent years, and this improvement will continue—through advances in seismology, new methods and channels of communication, and the contributions of basic and applied geophysical research.

In the meantime, the tsunami watch will be kept, and the people of the Pacific warned when the great waves roll across that largest ocean.

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Memorandum to the Reader

No aspect of Federal service to the public carries greater responsibility than that pertaining to the protection of life and property in this country and abroad. The U. S. Coast and Geodetic Survey is proud of the way in which the Seismic Sea-Wave Warning System has been able to answer one part of that responsibility—by serving all the people of the Pacific.

But the corollary of civil protection is public education. If the SSWWS is to achieve its best efficiency, the inhabitants of Pacific coastal areas must be educated to the dangers of tsunamis. This booklet is one step toward assisting local authorities in this matter of public education. Probably, you have begun to notice posters, small brochures, and other printed material on tsunamis in your post offices and other government buildings. This Bureau soon will release a half-hour color motion picture, entitled *Tsunami!* which will be available on loan without charge. A series of lectures has also been proposed, to acquaint the general public and cognizant local officials with some of the specifics of tsunamis.

We hope, through these means, to broadcast the dangers of tsunamis to all who may one day be forced to face the great waves.

H. Arnold Karo

H. Arnold Karo
Rear Admiral, USC&GS
Director

ADDITIONAL INFORMATION may be obtained on the phenomenon of tsunamis; the Seismic Sea-Wave Warning System; proposed networks operated at the local or regional level; and the U. S. Coast and Geodetic Survey generally—by writing:

Director
U. S. Coast and Geodetic Survey
Washington Science Center
Rockville, Maryland 20852